

REVIEW ARTICLE

## Making green infrastructure healthier infrastructure

Mare Löhmus, PhD, Associate Professor<sup>1,2\*</sup> and John Balbus, MD, MPH<sup>3</sup>

<sup>1</sup>Institute for Environmental Medicine, Karolinska Institutet, Stockholm, Sweden; <sup>2</sup>Centre for Occupational and Environmental Medicine, Stockholm County Council, Stockholm, Sweden; <sup>3</sup>National Institute of Environmental Health Sciences, Bethesda, MD, USA

Increasing urban green and blue structure is often pointed out to be critical for sustainable development and climate change adaptation, which has led to the rapid expansion of greening activities in cities throughout the world. This process is likely to have a direct impact on the citizens' quality of life and public health. However, alongside numerous benefits, green and blue infrastructure also has the potential to create unexpected, undesirable, side-effects for health. This paper considers several potential harmful public health effects that might result from increased urban biodiversity, urban bodies of water, and urban tree cover projects. It does so with the intent of improving awareness and motivating preventive measures when designing and initiating such projects. Although biodiversity has been found to be associated with physiological benefits for humans in several studies, efforts to increase the biodiversity of urban environments may also promote the introduction and survival of vector or host organisms for infectious pathogens with 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 play a crucial role in the urban climate adaptation and mitigation process. However, they also provide habitats for mosquitoes and toxic algal blooms. Finally, increasing urban green space may also adversely affect citizens allergic to pollen. Increased awareness of the potential hazards of urban green and blue infrastructure should not be a reason to stop or scale back projects. Instead, incorporating public health awareness and interventions into urban planning at the earliest stages can help insure that green and blue infrastructure achieves full potential for health promotion.

**Keywords:** *urban planning; urban wildlife; green infrastructure; blue infrastructure; ecosystem services; biodiversity; risk management; infectious diseases; climate change; adaptation*

\*Correspondence to: Mare Löhmus, Centre for Occupational and Environmental Medicine/SLSO, Solnavägen 4, 11365 Stockholm, Sweden, Email: mare.lohmus.sundstrom@ki.se

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Many countries and communities around the world are increasingly turning to development and expansion of green (vegetation-based) and blue (water-based) infrastructure to address a range of weather and climate adaptation challenges (1, 2). Drawing upon the concepts of ecosystem services, planners have incorporated green elements into previously concrete environments in increasingly innovative ways, with an aim to achieve multiple societal benefits. In the last decade, both the health and urban planning communities have become more engaged in studying the positive effects of greening the built environment, which include promoting physical activity, improving air quality, mitigating urban heat islands, and reducing exposures to waterborne pathogens (1, 3). Furthermore, epidemiological studies have found that people living close to green spaces or surrounded by a higher degree of greenness are healthier than people living farther away (4). A large

number of studies have suggested a positive effect of green space on health characteristics such as life expectancy (5), self-reported health (6), blood pressure (7, 8), noise annoyance (9, 10), birth weight (11), stress and salivary cortisol patterns (12), and more.

Alongside numerous benefits, however, green and blue infrastructure has the potential to create unexpected, undesirable side effects. Major water engineering projects have led to significant unintended harm to human health in the past. These include increased prevalence of human schistosomiasis resulting from dam constructions (13) and arsenic exposure in Bangladesh resulting from the construction of tube wells (14). Some possible disbenefits of green infrastructure have been mentioned in the literature, including increased air pollution from emissions of volatile organic compounds by urban trees (leading to increased ozone formation) (15), and the air circulation-limiting potential of tall, planted roadside vegetation (16). In most

cases, however, well-planned design features of green and blue infrastructure can mitigate unintended risks. The potential for health risks should thus not discourage development of green and blue infrastructure; rather, awareness of the potential risks and means of mitigating them should allow for the identification and mitigation of risks early in the planning process, rather than after the occurrence of human disease. Including public health perspectives in the early stages of urban planning may help avoid later unintended health problems and any associated mitigation costs.

This paper discusses potential public health risks stemming from increased urban biodiversity, urban bodies of water, and the allergenic effects of urban trees. In addition to considering the evidence for concerns in these areas, the paper also details possible methods for preventing or curbing potential problems.

### Cities and biodiversity – is more always protective?

As a result of habitat destruction and fragmentation, urban areas seldom support high levels of biodiversity. Even when project goals include increasing green area connectivity and biodiversity of modern cities (17–20), urban milieus will only in unusual cases become areas of high biodiversity or habitats for animals that have very specific requirements. Instead, the wild organisms inhabiting cities will most likely remain those that can more easily adapt to anthropogenic changes (21–23).

Biodiversity has been found to be associated with physiological benefits for humans in several studies (24, 25). However, these beneficial effects to human health appear to ensue from certain compositions of biodiversity rather than from simply adding numerically to the number of species found in a given area (26). Perhaps more importantly, when efforts are made to increase the biodiversity of urban environments for health reasons, it should not be forgotten that the desired species are not likely the only kind that will find its way to the green areas. In addition to desired species, an array of so-called pest organisms (and, with changing climate, also new and unexpected organisms) are also likely to benefit from these efforts, with potentially harmful consequences.

In recent years, the disease-protective effects of biodiversity have gained a lot of popularity (26). These ideas are mainly based on two related concepts: zooprophylaxis and dilution effect (26). The basis of the zooprophylaxis idea has its origin in the discipline of malaria epidemiology (27). It suggested that because different species of vertebrates are often less competent than humans to support the transmission of malaria, increasing the number of animals around humans protects them by diverting mosquito bites towards less competent hosts. The ‘dilution effect’ hypothesis originated from the case of tick-borne Lyme disease caused by the bacteria *Borrelia burgdorferi*.

This hypothesis proposed that, by increasing the biodiversity in a wildlife community, the *Borrelia* transmission-competent host species would generally be ‘diluted’ with non-competent host species, which would lead to a reduced probability that an infected tick would feed on a competent host and thus result in a lower abundance of infected ticks (28–30). The main difference between the concepts of zooprophylaxis and dilution effect is that although zooprophylaxis reduces the contact rate between infected vectors and humans, it does not necessarily reduce the infection rate of the vectors, whereas dilution reduces the rate of infected vectors, but not their contact rates with humans (26). These ideas have been applied to many different diseases since they were proposed and have become important justifications for wildlife conservation and increased biodiversity (26). However, these ideas raise some very important questions; for example: how much biodiversity is needed for the dilution effect to occur – Is the relationship linear? Is there a threshold value? Are all increases in biodiversity positive?

In a review from 2012, Randolph and Dobson (26) critiqued the biodiversity-buffers-disease paradigm, arguing that although the concepts of zooprophylaxis and dilution effect may be biologically sound in certain simple systems, in complex systems they are likely to apply only in occasional, extreme, situations. They suggest that dilution or amplification of a disease depends more on the *composition* of the wildlife community than on biodiversity *per se*, and conclude that the possible positive relationship between biodiversity and the dilution effect is definitely not linear, not even in case of tick-borne diseases (26). In fact, in several studies, decreased disease prevalence has resulted from the high density of just one particular non-competent host, rather than from greater biodiversity *per se* (26, 31–33). Moreover, in some cases, adding a non-competent host might instead increase both the disease vector abundance and the risk of being bitten by the vector (e.g., example of deer and *Ixodes ricinus* ticks in the next section). Adding a competent host species to the local fauna may become a key factor that allows a sudden dispersion of a novel pathogen into new areas (26). Therefore, although protecting biodiversity and ecosystem function is generally a very welcome approach, new species in city environments might not always have a disease-protective value (34).

### ‘Unintended’ biodiversity – urban pests and disease vectors

#### *Ticks, biodiversity, and green space*

Increasing the amount of green spaces and connectivity between them has the potential to affect the likelihood of encountering the most prominent arthropod disease vector at northern latitudes – the tick (35, 36). The occurrence of ticks is highly dependent on the movement of their hosts

and permanent tick populations are supported by habitat network (35, 36). Several studies have reported frequent occurrence of ticks and potentially zoonotic tick-borne pathogens in urban locations (34, 37–40). Junttila et al. (37), for example, estimated the density of *Ixodes ricinus* ticks in popular recreational areas of Helsinki, Finland, to be 1–36 ticks/100 m, and depending on the location, the tick infection rate with *B. burgdorferi* varied between 19 and 55%. The most abundant potential hosts of ticks in Helsinki were small rodents and insectivores. However, the areas with greatest population densities of ticks were those supporting a permanent hare (*Lepus timidus*) population (37). In the suburban and urban forests of the cities of Gdansk, Sopot, and Gdynia in Poland, 14% of *I. ricinus* ticks were infected with *Anaplasma phagocytophilum* (the causal agent of human granulocytic anaplasmosis), 12.4% with *B. burgdorferi*, and 2.3% with *Babesia microti* (a common causal agent of human babesiosis) (40). Schorn et al. (34) investigated a selection of Bavarian public parks in Germany and found that up to 7.7% of ticks in the parks were infected with potentially zoonotic *Rickettsia* spp. *A. phagocytophilum* was detected in high prevalences (up to 20.1%) in another Bavarian park study, even when the roe deer (*Capreolus capreolus*), which is suggested to be the main reservoir for this pathogen, was missing (39). However, *Babesia* spp. positive ticks were only found in Bavarian parks that supported a permanent population of deer (34). These studies show a considerable risk of encountering a zoonotic tick-borne infection in urban green environments. Furthermore, the recent, possibly climate-change-induced, increase in the number of ticks, coupled with the geographic extension of their habitats, has increased the risk of tick-borne infections in both humans and pets, while also causing cases of tick-borne infections in new areas (41, 42).

One important regulator of tick abundance is the occurrence of cervides (members of the deer family). A positive relationship between deer density and the abundance of ticks has been reported in several studies (26, 43–45). Increasing the size of, and connectivity between, urban green areas may attract more frequent visits from deer (46). Because deer are not a competent reservoir for the tick-borne encephalitis virus and *B. burgdorferi*, it has been suggested that increased numbers of deer reduces the occurrence of these pathogens in the long run (45, 47–49). This negative relationship has been presented as a textbook example of the previously mentioned dilution effect (29). Because deer are an attractive host for the nymphs of *I. ricinus*, but an incompetent vector for *B. burgdorferi*, they might be expected to divert the nymphs from feeding on competent reservoirs (such as rodents), thereby theoretically reducing transmission (26, 45). Unfortunately, several other studies have observed an increase in the incidence of Lyme borreliosis with increased deer densities and distribution (50–52). This is because, as Randolph

and Dobson (26) point out, even if the *proportion* of infected vectors decreases in the presence of a non-competent vector (in this case the deer), the *actual numbers* of infected ticks may still increase. Furthermore, other tick-borne diseases, such as *Babesia* spp. and *Anaplasma*, benefit from or even require the presence of deer, thus making the occurrence of Cervides a prerequisite for their transmission.

Increased connectivity between urban green areas may boost the number of ticks in areas otherwise too small to house a resident population of deer, simply by increasing the frequency of deer passage and the accompanying deposition of adult ticks. Consequently, when increasing the size, connectivity, and biodiversity of urban green areas, more attention should be paid to preventive steps to avoid human infections with tick-borne pathogens. First steps for prevention include calling people's attention to the existence of ticks in urban milieus and providing guidance on methods to avoid tick attacks, recognize attached ticks, and remove ticks properly (40).

Several methods for managing tick densities have been tested. Ticks have occasionally been controlled with a variety of chemical sprays and applications (53), but this approach is not recommended because its results are temporary and always threaten harmless non-target species. Specific targeted solutions – focusing on decreasing the number of infected small mammals in the environment – have also been tested. In the eastern United States, pyrethrin-soaked cotton fibers were provided as nesting material for small mammal hosts and resulted in elimination of immature ticks in rodent nests; however, the same control method may not be equally applicable in different ecological contexts. For example, the same treatment did not produce the desired result in California (53). In a 5-year trial, Richer et al. (54) tested delivering OspA-based transmission-blocking vaccine against *B. burgdorferi* to wild white-footed mice (*Peromyscus leucopus*) via oral baits. This treatment led to a 23 and 76% reduction of the nymphal infections during a 2- and 5-year period, respectively. Furthermore, significant decreases in tick infection prevalence were observed within 3 years of vaccine deployment. In cases where vaccination programs and increased public awareness are not enough to prevent high numbers of tick-borne disease events, these targeted solutions that decrease the disease prevalence in potential host reservoirs rather than in vectors appear to be the most likely path for managing the risk of tick-borne illnesses.

### **Urban rats, biodiversity, and green space**

The brown rat (*Rattus norvegicus*) is a species with impressively high adaptive potential. It can be found in almost all habitats worldwide. Humans often provide rats with an abundance of supportive resources and favorable microclimatic conditions, allowing rat populations to

grow, especially in areas where the numbers of their natural predators are greatly reduced (55, 56).

An overpopulation of rats is a serious problem in many modern cities and can cause severe problems for humans, including gnawing damage, spread of rat allergens, and transmission of zoonotic pathogens (56, 57). Rats are hosts for a wide range of zoonotic diseases, including parasitic helminthes (e.g. *Calodium hepaticum*, *Echinococcus multilocularis*, *Hymenolepis* spp.), bacteria (e.g. species of *Leptospira*, *Listeria*, *Salmonella*, *Yersinia*), protozoa (e.g. *Cryptosporidium* spp., *Toxoplasma gondii*, *Giardia* spp.), and viruses (e.g. Seoul hantavirus, hepatitis E, *Coxiella burnetii*, and even rabies) (58–60). In some cases (e.g. Seoul virus and *Leptospira* spp.), transmission of rodent diseases with zoonotic potential does not require an actual confrontation with the animal, but can result from inhaling the aerosol from rat feces or urine (56). A great number of ectoparasitic organisms, such as fleas, ticks, mites, and lice, are very common on rats and function as vectors for a number of serious diseases (e.g. Lyme disease, typhus, and plague) (56, 61). Furthermore, rat allergen sensitization and exposure has been associated with increased asthma morbidity in inner-city children (57).

Urban rats usually live in groups consisting of related individuals and show strong site fidelity (59, 62, 63). However, when encountering resource shortage or habitat disturbance, rats have been observed to move up to 11.5 km (62, 63). The presence of food, vegetation, shelter, and natural soil for burrows in the absence of anthropogenic shelters) are essential factors for city rats. Consequently, highly vegetated urban areas, such as parklands and patches with high tree cover and many shrubs, may support the existence of local rat populations (59, 64, 65). The presence of trees, especially deciduous trees, rich bank vegetation, an abundance of seasonal fruits, and patches with ruderal vegetation increase habitat suitability for rats (59). Because the brown rat prefers close proximity to water, it thrives near ponds and rivers, especially in areas where people feed wild birds (64, 65). Outbreaks of leptospirosis (a disease typically carried by rats) associated with swimming in town ponds have been mentioned in the literature (66). Other, potentially rat-borne, infectious disease agents, such as *Campylobacter*, *Salmonella*, and enterohemorrhagic *Escherichia coli*, are frequently found in water samples collected from urban bodies of water (61, 67, 68); however, the contribution of rats in contaminating the water bodies with these pathogens is not well known.

Habitat suitability alone, however, does not automatically lead to an explosion of rats, because rats can colonize only in suitable environments if there is an available route for rodents to move into the area (e.g. through railways, waterways, sewage systems, or other types of habitat connectivity) (59, 65). Traffic roads, for example, act as

barriers for rat movement, and thus urban parks surrounded by heavy traffic are often free from rats (59, 62, 69). Increasing the connectivity between green areas in modern cities would also increase the opportunity for rat dispersal. This may be offset by an increase in the number of potential rodent predators, such as foxes, coyotes, or birds of prey. Nevertheless, it is important to assess the possibility that more green connectivity in urban areas may potentially facilitate the spread of infectious diseases between geographically distant rat populations.

In certain cases, increasing the biodiversity of rodent predators may foster the introduction of certain pathogens into urban landscapes. For example, the dispersal of parasites with multiple host systems, whose life history involves intermediate and final hosts belonging to different taxa, may especially be facilitated. The recent increase of foxes (*Vulpes vulpes*) in European cities has allowed the infamous small fox tapeworm (*E. multilocularis*), which causes human alveolar echinococcosis, to move into urban areas (70). The life cycle of this parasite typically includes canines (such as foxes, genera *Vulpes* and *Alopex*, and coyotes) as definitive hosts and different species of rodents as intermediate hosts. The presence of foxes in the cities has thus increased the likelihood of *E. multilocularis* occurring in city rodents and also increased the infection risk of domestic dogs and cats that prey on rodents (70).

There are unfortunately no shortcuts for preventing urban green space from becoming infested with rats; a proper and consistent local rat management program is necessary. Rodent control, past and present, typically involves various trapping methods and rodenticides. However, rodenticide use should be strongly discouraged, as side effects on non-target species may be devastating (71–73). Furthermore, many rodent species have been shown to become resistant to the most commonly used rodenticides (74). Consequently, developing methods of rodent control that are both efficient and lenient to other wildlife is of high importance. A shift away from poisons and toward applied management has been effective at controlling rat populations in the long term (69, 75, 76). Such management methods include preventive design in landscape structures (e.g. reducing the amount of densely planted evergreens in parks), sanitation of garbage stations, reducing food availability by decreasing vegetation that produces excessive amounts of fruit, and breaking links between populations in resource-rich patches. Thus, adaptation measures that expand the amount of green space in urban areas need to also ensure that the green space is structured in a way that reduces its carrying capacity for urban rat populations and decreases the capacity to transmit infectious diseases.

### Urban bodies of water and wetlands

Constructing and restoring wetlands and bodies of water in urban areas is steadily gaining popularity (77, 78).

The main reasons are the ecosystem services that they provide: storm water retention, erosion and flood control, water quality improvement, plant and animal community maintenance, and carbon sequestration. Bodies of water and wetlands also strengthen the ecological food chain and are aesthetically appealing (77–79). Furthermore, introducing open surface water in urban design is thought to reduce inner city temperatures (80). Consequently, bodies of water and wetlands play a crucial role in urban climate change adaptation and mitigation processes. However, in addition to their many benefits, there is cause for concern about the potential nuisance and health threats these structures could create, by, for example, providing habitats for mosquitoes and endangering humans (especially children), pets, and wildlife during toxic algal blooms.

### **Mosquitoes in urban water bodies**

Mosquitoes need water to reproduce. Although some species of mosquitoes (e.g. certain *Aedes* spp.) (81) are able to breed in containers, sewers, gutters, and other small collections of water in urban spaces, urban water bodies also serve as important breeding areas (82). The predominant public concern about mosquitoes typically involves their capacity to spread serious infectious diseases. Species of *Culex* mosquitoes, for example, are abundant over wide geographic areas and common in urban milieus (82). They function as the main vectors of many arboviruses including West Nile virus and St. Louis encephalitis virus (79). Similarly, the mosquito, *Anopheles quadrimaculatus*, which is the dominant malaria vector in North America, can be found in many regions in urban areas (79, 82). Container breeding species from the genus *Aedes*, especially *A. albopictus* and *A. aegypti*, spread several serious viral diseases such as dengue fever, chikungunya, and yellow fever, outbreaks of which are common in numerous urban landscapes in tropical and subtropical areas (83–86). In addition to the severity of health threats of mosquito-borne diseases, the nuisance factor of mosquitoes can seriously affect the quality of life for humans (82, 84).

Constructed wet environments are of concern because densities of larval populations in these can greatly exceed those in natural environments (82). According to a study comparing the occurrence and abundance of mosquito larvae in constructed wet environments (ditches, retention ponds, detention ponds) and natural wetlands (marshes, flood areas, creeks and rivers) in the Upper Midwest United States, constructed bodies of water were the predominant producers of mosquitoes in urban environments (87). Other recent studies have documented the importance of water bodies in urban parks as breeding grounds for disease-carrying mosquitoes in Sao Paulo, Brazil (88, 89). Even some species of *Aedes* mosquitoes (contributing to the dispersal of arboviruses in Australia,

e.g. *Ae. bancroftianus*, *Ae. sagax*, *Ae. theobaldi*, and *Ae. vittiger*) that are typically found in temporary pools on floodplains after seasonal rains, breed at the margins of wetlands following natural or other fluctuations in water levels (82). Unlike small containers and urban sewers, urban wetlands and water bodies also provide suitable habitat for bird species, which increases the possibility of transmission of viral vector-borne diseases to nearby human populations (90).

Stagnant, shallow water is the primary factor associated with high mosquito larvae counts (79, 82) and characterizes many constructed wet environments. Therefore, when constructing urban aquatic elements and recreational bodies of water (e.g. duck ponds), special attention should be spent on inducing sufficient amount of water movement by adding easily available and well-known components, such as pond pumps, waterfalls, fountains, or aerators (82, 91). The recent spread of the Asian tiger mosquito, *A. albopictus*, in southern Europe and the US has led to governmental warnings in a number of countries, resulting in increased public awareness about how to avoid the reproduction of container-breeding mosquito species (92). However, the importance of also avoiding mosquito breeding from larger intentionally (or un-intentionally) created waterbodies is often overlooked, as suggested by various reports of poorly designed landscape details contributing to production of troublesome numbers of mosquitoes (93–97). As climate adaptation and other green concerns encourage the construction of bodies of water and wetlands in modern cities, making these less conducive to mosquito reproduction should be taken seriously.

Another factor that may differ between natural and constructed bodies of water is the lack of natural predators. The importance of larval predators to constrain mosquito populations is obvious from several studies (79, 87). Mosquito larvae survival is usually lower in bodies of water that contain high numbers of macro-invertebrates (such as water boatmen, backswimmers, predacious diving beetles, water striders, dragonflies) which feed on mosquito larvae, and with presence of vertebrate predators like salamander larvae and native fish (79, 87). In many cases, sustainable predator populations do not develop in constructed bodies of water because of the difficulty of establishing conditions that support the life-requirements of the predators (79). Nonetheless, increasing the number of aquatic predators and ecosystem complexity should be encouraged in urban wetland planning as a means of reducing the threats of mosquito proliferation.

Higher mosquito larval densities are also connected to high conductivity and low dissolved oxygen content (79). High conductivity is associated with the availability of favorable food sources for mosquito larvae. Low dissolved oxygen is not favorable for the larvae *per se*, as the mosquito larvae are surface breathers and therefore not

influenced by the water oxygen content, but it may limit the abundance of their predators and thereby increase mosquito survival.

The type and amount of aquatic vegetation also affects the size of mosquito populations. Dense vegetation, in combination with increased inflow of nutrients, contributes significantly to internal loading of nitrogen in the water bodies, leading to even more overgrowth (98). Increased overgrowth gives rise to low dissolved oxygen levels, creates stagnant water areas, and reduces the diversity of wildlife habitat (98). Thus, dense emergent vegetation throughout the pond periphery may create a habitat that, in addition to providing many favorable oviposition sites for mosquitoes, is also not a suitable habitat for the natural predators of mosquito larvae (79). Consequently, proper maintenance of bodies of water to prevent overgrowth of vegetation can help to keep mosquito populations under control (79, 82, 98).

#### **Algae and cyanobacteria in urban ponds**

Low water circulation and overabundant nutrient input in urban ponds can lead to severe water quality problems such as an intensive growth of algae and cyanobacteria and to the development of toxic blooms (99). Excessive growth of filamentous algae, such as the green algae from genus *Spirogyra* and *Cladophora*, and several species of cyanobacteria (e.g. *Microcystis aeruginosa*, *Anabaena circinalis*, *Anabaena flos-aquae*, *Aphanizomenon flos-aquae*, and *Cylindrospermopsis raciborskii*) is a common problem in urban ponds (99–102). Especially in ponds that contain areas with shallow stagnant water where the light can penetrate the bottom, these algae grow, cover the rocks and plants, and eventually form long chains of cells that entwine and create dense multi-species cotton- or slime-like mats (103, 104). As the algae photosynthesize, they produce bubbles of oxygen which can become trapped in the mats and lift them up to the surface of the pond. The algal mats are not just unsightly; they also interfere with recreation activities such as fishing and swimming, and because dying algae emit a bad odor, they may detract from an area's pleasantness (103). Furthermore, on warm summer nights and during periods of windless cloudy weather, algal photosynthesis may be overtaken by respiration. Algae consuming more oxygen than they emit can lead to low levels of dissolved oxygen in the water, killing fish and other aquatic organisms and contributing to the increased survival of mosquito larvae in relation to other aquatic species (79, 103, 104).

Algal blooms sometimes produce phytotoxins. In freshwater systems, toxins are most commonly produced by cyanobacterial species (99). Numerous cyanobacteria are able to produce toxins with either neurotoxic or hepatotoxic qualities (105). Microcystins, nodularins, and cylindrospermopsin are some of the hepatotoxins that can be produced by a number of cyanobacterial genera

(102, 106, 107). When ingested, hepatotoxins may cause vomiting, diarrhea, abdominal pain, loss of appetite, abnormal behavior, yellowing of the skin and mucous membranes, and in most extreme causes, acute liver failure (108). Some hepatotoxins (e.g. nodularins and microcystins) can also act as tumor promoters (102). Neurotoxins, such as anatoxin-a(s), saxitoxin, neosaxitoxin, and  $\beta$ -methylamino-L-alanine (BMAA), can be produced by several cyanobacterial taxa and affect the nervous system of exposed organisms in various ways (102, 109, 110). Neurotoxic symptoms in animals, for example in dogs that have been swimming in or drinking from affected ponds, include salivation, weakness, unsteadiness, muscle cramps, twitching, and difficulty breathing. Severely affected animals can develop seizures, heart failure, paralysis, and die even with prompt and appropriate treatment (110). Consuming aquatic organisms with high levels of accumulated BMAA is associated with devastating neurodegenerative diseases belonging to the amyotrophic lateral sclerosis/parkinsonism-dementia complex in humans (105, 109).

Algal blooms in urban ponds generally pose less of a threat to humans, as they do not consume water as pets do (104). However, children with low body mass who swim in the ponds or play with the water may be seriously affected by relatively low doses of toxins and should therefore avoid contact with pond water during the blooms. Even when not ingested, neuro- and hepatotoxins can cause skin rashes and irritation of the nose, eyes, and/or throat on contact (104, 111). Consequently, algal growth in urban bodies of water is an important health concern and should be prevented by correct construction.

Preventing excess algal growth is preferable to and less costly than trying to control it once it occurs. Mechanically removing large clumps of algae from ponds is only a short-term solution, and although applying chemicals works as a short-term control method, their usage threatens other aquatic organisms (103). The primary method for preventing algal blooms is decreasing nutrient input to the pond (104). To reduce local erosion and runoff of nutrients, one can establish a buffer strip of undisturbed vegetation around the pond; for instance, the grass should never be cut to the edge of the pond and the grass clippings should never be dumped in the pond or close to the pond's edge (99, 103). However, as discussed above, a buffer strip of undisturbed vegetation around the pond may become a popular habitat for rats, if the rodent management procedures are not carried out properly. Feeding fish and birds at the ponds should be discouraged. Water movement and aeration of the water are also essential. Increasing the incline of the sides of the pond can help eliminate shallow areas where sunlight reaches the bottom of the pond (103). However, in recreational areas visited by families with small children, safety issues must be considered before deepening ponds and steepening

their edges. Biological control by using natural predators has occasionally succeeded but requires further evaluation (112).

### **Pollen – a potential downside of green zones?**

Increasing the number of green roofs, green facades, green ornaments, and planted trees is becoming popular and increasingly encouraged by modern city planners, as these installations provide ecosystem services including improved storm-water management, better regulation of building temperatures, reduced urban heat-island effects, and increased urban wildlife habitat (113, 114). Whereas many studies suggest that green structures may benefit both the mental and physical health of city populations (115, 116), increasing urban green space may adversely affect citizens allergic to pollen (117).

Allergic respiratory response to pollen (pollinosis) is a very common public health problem that is increasing worldwide in both prevalence and severity (118). The prevalence of pollinosis at some European locations is presently estimated to be up to 40% and its cost in terms of impaired work fitness, sick leave, consulting physicians, and drugs is considerable (119). Because exposure to pollen is strongly influenced by meteorological factors such as temperature, sunlight, humidity, and thunderstorms; and by ambient levels of air pollution, future pollinosis exposure will be strongly affected by climate change and air pollution regulation enforcement (120).

Plants that rely on the wind to carry pollen are the primary contributors to pollinosis. Pollen allergy is not caused by a reaction to entire pollen grains, but rather by reaction to certain proteins (the allergens) present in or on the pollen grains. Pollen grains usually carry several allergens that may each separately cause symptoms. A wide variety of trees (e.g. genera of birch, *Betula*, alder, *Alnus*, hazel, *Corylus*, oak, *Quercus*, olive, *Olea*, and cypress, *Cupressus*), weeds (e.g. ragweeds, *Ambrosia artemisiifolia*, *A. trifida*, mugworts, *Artemisia vulgaris*, *A. annua* and *A. verlotum* and nettles, *Parietaria judaica*, *P. officinalis*), and grasses (e.g. timothy, *Phleum pratense*, orchard grass, *Dactylis glomerata*, meadow foxtail, *Alopecurus pratensis*) are common producers of urban aeroallergens depending on geographic location (118).

The composition of urban vegetation is often characterized by an overabundance of a few specific species, most commonly used as ornamental plantings (117). In numerous cases, these ornamental species produce large amounts of pollen with high allergenicity which has a detrimental effect on local residents (117). In many cities, it is a common practice to use closely planted individuals of a single tree species (i.e. Cupressaceae, *Populus* spp., *Phenix* spp., *Ulmus* spp.) to line avenues and form anti-noise barriers. However, lining the roadsides with tightly planted trees may reduce the ventilation and air currents around the roads (16) which would otherwise dilute the pollen

(and also the air pollutant) concentrations. As a result, streets may end up with a row of ‘chimneys’ that are simultaneously releasing large amounts of pollen and limiting their dispersion by air currents, thus seriously affecting the local micro-environmental conditions (117).

The introduction of exotic species in urban areas can sometimes trigger new allergies among urban residents. For example, *Betula* spp., which has recently become popular as an ornamental plant by landscape architects in Italy, has caused a significant increase in allergic sensitization to birch allergens (118). Similarly, the introduction of the Australian pine species (*Casuarina* spp.) in Spain and of *Eucalyptus* species in Italy (121) has led to sensitization to new allergens among the local citizens.

Commonly, urban areas differ from rural ones by relatively high levels of air pollutants, such as nitrogen oxides, ozone, sulfur dioxide, and particulate matter of various sizes. Increased concentrations of these pollutants are known to have toxic effects on respiratory tract and an adjuvant effect on respiratory hypersensitivity and asthma (122, 123). Exposure to air pollutants may exacerbate the development of pollen allergy and has been suggested to be an explanation of why the people living in urban areas are 20% more likely to suffer pollen allergies than people living in rural areas (118, 123, 124). Additionally, pollutants also mechanically interact with airborne pollen grains, triggering release of allergen-containing granules from pollen and thereby increasing the bioavailability of airborne allergens (125). Combining all these interactions between air pollutants and pollen, urban citizens may become especially vulnerable to pollen allergens.

These findings emphasize the need for developing guidelines regarding the planting of urban green areas with low allergic impact (117). Planting insect-pollinated plants instead of wind-pollinated ones, carefully controlling the allergic potential of new exotic species, and actively consulting with botanist/palynologists when selecting the most suitable species (117), are some of the proposals that can make future green spaces ‘healthier’ for people that are allergic to pollen.

### **Conclusions**

Optimizing ecosystems services in urban settings is a critical part of successful adaptation to climate change and assuring the sustainability of urban communities. But optimization should include identification of potential negative health consequences and incorporation of features to mitigate or eliminate potential health risks. Ecosystem features that enhance biodiversity and the introduction or reestablishment of new species in urban areas have the potential to foster the transmission of vector-borne and zoonotic diseases. Optimization will also involve trade-offs within measures to address public health risks. For example, designing water features with steep sides and limited emergent vegetation helps limit mosquito

breeding and algal growth, but can make the ponds more dangerous for children or pets to wade in. Similarly, maintaining a strip of undisturbed vegetation around a pond may help limit algal growth in a pond but at the same time it can provide attractive habitat for rats and other rodents. Consideration of potential risks and trade-offs should be made on a case-by-case basis and decisions made based on site characteristics, prevalent public health concerns, and community priorities.

Increased understanding of the complex life cycles of disease agents and vectors in urban settings can help with the development of effective ecosystem interventions to reduce risks. Basic public health approaches, including public education, monitoring and surveillance, and vector control, may need to be augmented in the initial stages of new green and blue infrastructure projects to detect and mitigate potential health risks. For urban water features, design elements that impede the growth of pathogens and toxic algae, as well as make those water features less attractive habitat for disease-carrying animals are important considerations in the early planning stages. Finally, thoughtful selection of tree species in highly populated areas can help avoid increasing pollen concentrations and related disease burden in allergic residents. Increased awareness of the potential hazards of urban green and blue infrastructure should not be a reason to stop or scale back projects. Instead, incorporating public health awareness and interventions into urban planning at the earliest stages can help insure that green and blue infrastructure promotes health to the fullest extent possible.

### Disclaimer

This article is the work product of an employee of the National Institutes of Health (NIH); however, the statements, opinions, or conclusions contained therein do not necessarily represent the statements, opinions, or conclusions of the NIH; its component institutes and centers; or the United States government. The authors declare they have no actual or potential competing financial interests.

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