Biodiverse green spaces: a prescription for global urban health

Emily J Flies[1,2]*, Chris Skelly[3,4], Sagri Singh Negi[5], Poornima Prabhakaran[5], Qiyong Liu[6,7], Keke Liu[6], Fiona C Goldizen[8], Chris Lease[9], and Philip Weinstein[1]

The world is urbanizing and chronic health conditions associated with urban living are on the rise. There is mounting evidence that people with a diverse microbiome (bacteria that inhabit the human body) or who interact with green spaces enjoy better health. However, studies have yet to directly examine how biodiverse urban green spaces (BUGS) might modify the human microbiome and reduce chronic disease. Here we highlight the potential for green spaces to improve health by exposing people to environmental microorganisms that diversify human microbiomes and help regulate immune function. We present four international perspectives (from Australia, China, India, and the UK) on the major challenges and benefits of using BUGS to alleviate health burdens. We propose solutions to these challenges and outline studies that can test the connections between BUGS, immune function, and human health and provide the evidence base for effective BUGS design and use. If further studies reinforce this hypothesis, then BUGS may become a viable tool to stem the global burden of urban-associated chronic diseases.

Front Ecol Environ 2017; 15(9): 510–516, doi: 10.1002/fee.1630

Currently, over one-half of the global population lives in urban areas, and over two-thirds are expected to be urban by 2050 (World Bank 2015). Although urbanization provides economic, social, and educational benefits, urban areas also have higher rates of allergic, autoimmune, and inflammatory diseases ("immunological diseases") associated with immune system dysfunction (Bach 2002; von Hertzen *et al*. 2011; Rook 2012).

The relationship between allergies and urban living has been recognized for over a century but the underlying causes for the higher rates of immunological diseases in urban areas are just starting to be revealed (Bach 2002; Rook 2012). Immunological diseases including allergies, asthma, diabetes, inflammatory bowel diseases, multiple sclerosis, and even diseases not traditionally considered immunological (eg obesity and depression) are increasingly being linked to the bacteria that inhabit the human body (ie the human microbiome; Bach 2002; von Hertzen *et al.* 2011, 2015; Rook 2012, 2013; Haahtela *et al.* 2013); specific examples are listed in Figure 1 (with corresponding citations in WebTable 2). However, the precise mechanisms by which the urban environment has altered human microbiomes, and how those microbiomes can help to restore proper immune function, are less well known.

Urban areas often have depleted biodiversity (Aronson *et al*. 2014), and many people in urban spaces have little exposure to natural settings. Importantly, urban humans also have a less diverse gut microbiome (Schnorr *et al.* 2014), and it is becoming increasingly clear that a diverse microbiome is essential to human health (WHO and CBD 2015). The potential to optimize health and immune function by manipulating the human microbiome via the environment is an unproven but appealing strategy and could have a very large impact on public health. We review the evidence that immunological diseases are connected to an altered microbiome, and propose that biodiverse urban green spaces (BUGS) could play a role in reducing the growing burden of such diseases in urban settings.

In a nutshell:

- Chronic diseases associated with compromised immune function have become a major global problem, especially in urban areas
- The potential for biodiverse urban green spaces (BUGS) to reduce the global chronic health burden is tantalizing but empirical evidence is lacking
- Before BUGS can be used to improve global urban health, we need robust experimental studies to clarify the mechanisms connecting green space and human health, and identification of the microbial species (if any) and the types of green space interaction (behaviors) responsible for observed health benefits
- Studies in developing nations and improved international awareness and uptake will also be required

*[1]School of Biological Sciences, University of Adelaide, Adelaide, Australia; [2]School of Biological Sciences, University of Tasmania, Hobart, Australia *(emily.flies@utas.edu.au); [3]Public Health Dorset, Dorchester, UK; [4]Primary Care & Population Science, University of Southampton, Southampton, UK; [5]Public Health Foundation of India, Gurgaon, India;* *continued on last page*

The myriad benefits of interacting with green space

Functional ecosystems provide numerous benefits to humans in the form of ecosystem services, including food provisioning, climate regulation, and support of nutrient cycles, along with many well-established health benefits (MA 2005; WHO and CBD 2015). There is similarly strong evidence showing that interaction with nature can result in a variety of psychological and physical health benefits (Figure 1; WebTables 1 and 2). Green space health benefits (GSHB) are diverse and range from improved cognitive function to reduced obesity and improved birth weights (WebTables 1 and 2). Nevertheless, the mechanisms connecting green spaces to health benefits are not always clear. Experimental "forest bathing" studies have shown that simply walking or spending time in a forest can improve immune function for up to one month (Li 2010), and recent reviews suggest that altered immune function may underlie many of the observed GSHB (Figure 1; Rook 2013; Kuo 2015). However, what causes the altered immune function is unclear, and there must be a long-term effector to link chronic diseases to green space interaction. We therefore endorse the hypothesis (Hanski *et al.* 2012; Haahtela *et al.* 2013; Rook 2013; von Hertzen *et al.* 2015) that interactions with green space alter the human microbiome, which acts in the long term to suppress inflammation and reduce chronic immunological diseases.

New and improved versions of the hygiene hypothesis

The "biodiversity" hypothesis and the "old friends" hypothesis are adaptations of the "hygiene" hypothesis (Strachan 1989) – all of which argue that immunological diseases are the result of a disconnect between contemporary humans and the diverse microbial world in which human life has evolved (von Hertzen *et al.* 2011; Hanski *et al.* 2012; Rook 2012, 2013; Haahtela *et al.* 2013). The hygiene hypothesis laid the foundation for this concept by connecting allergic diseases to a reduced exposure to microbes (due to improved hygiene in developed societies). The old friends and biodiversity hypotheses extend beyond allergies and claim that the whole immune system can become unbalanced and lead to myriad diseases when humans are not exposed to a diversity of microbes (biodiversity hypothesis) or the specific microbes with which we have evolved (old friends hypothesis).

The human microbiome is populated before and after birth with microbes (and microbial products) from vaginal secretions, breastmilk, and contact with close family members, and immediately begins molding the host immune system. Inadequate microbiome acquisition during the postnatal period has been connected to inflammatory disorders such as asthma, inflammatory bowel disease, necrotizing enterocolitis, allergies, and obesity (Arrieta *et al.* 2014). Yet the human microbiome is also malleable and changes during the course of our lives due to environmental (including water and dietary) exposure (David *et al.* 2014).

Proximity to farms, farming practices, and agricultural spaces is associated with increased diversity in airborne and skin-based microbiota, increased anti-inflammatory

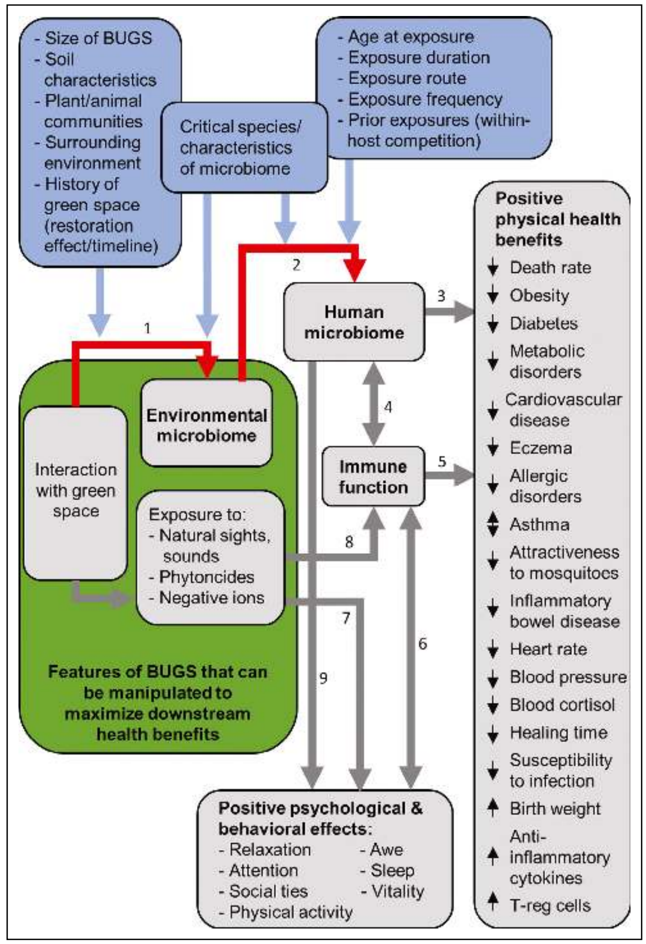

Figure 1. *Potential pathways linking green space, microbiomes, and health. Gray lines have empirical data to support the links, whereas red lines represent the potential missing links that are the focus of this paper. Blue boxes and arrows represent questions that could influence the effect of the indicated relationships. Inspired by Figure 2 in Kuo (2015). Numbers indicate corresponding references in WebTable 1.*

cytokines (Hanski *et al.* 2012), reduced rates of asthma and allergies (Lewis 2000), and reduced inflammatory bowel diseases (Radon *et al.* 2007). These findings have prompted the idea that modifying the environment to which people are exposed could reduce the frequency and severity of immunological diseases.

We encourage a practical application of the biodiversity hypothesis: using BUGS to improve urban microbiomes and public health. Despite the vast potential for BUGS to alleviate the global urban health burden, a critical knowledge gap exists between the environmental microbiome and the human microbiome. Scientists do not yet know: (1) how the environmental microbiome influences the human microbiome, (2) what sorts of interactions with the environment reliably alter the human microbiome, and (3) what features of the environment or environmental microbiome have the greatest impact on human health (WHO and CBD 2015). These gaps need to be bridged with a strong evidence base if practitioners are to effectively design urban green spaces to improve human health.

Using BUGS to improve global urban health

Before attempting to mitigate the world's rising urban-associated immunological disease problems through BUGS, scientists must first understand the challenges and benefits for those involved in the creation and implementation of public health policy, particularly in heavily urbanized and rapidly urbanizing countries.

Currently, India and China have urban populations of 440 million (33% of the country's total population) and 782 million (57% of the country's total population), respectively; by 2050, the urban component of the two countries' total populations is predicted to rise to 50% and 76%, respectively (World Bank 2015). These two countries have the most to gain from avoiding the chronic inflammatory disease epidemic occurring in more urban countries. Australia and the UK (where 90% and 82% of the total population is urban, respectively), are starting to recognize the value of BUGS and are beginning to identify the challenges of and solutions for using BUGS as a tool to improve public health. It is these unique international perspectives that we now present. We also summarize the main concerns of the public health professionals and propose solutions to those concerns in Table 1.

BUGS in four countries

Australia

Though vast expanses of the Australian continent remain uninhabited, the Australian population is one of the most urbanized in the world, and Australian cities are now facing space limitation problems. Although urban intensification helps protect nearby biomes, it puts considerable pressure on green spaces within city limits.

Currently, most Australian states explicitly aim to protect urban green spaces but because the goals are usually to preserve animal habitats and provide recreational areas for people, human health benefits may not be maximized. One state (South Australia) has released a "Healthy parks, healthy people" initiative, specifically recognizing the potential for microbial biodiversity in parks to benefit human health via immune modulation. However, it is currently unclear whether and how this awareness will translate to action.

Some states also have urban green space incentive schemes to encourage the inclusion of natural areas into their cities. In practice, urban developers often elect to contribute money to these schemes rather than incorporate green space into their development plans. While this results in fewer or smaller (Figure 2a) urban green spaces, it does mean that funds are available to improve the green spaces that remain.

Before city planners can leverage such funds to create optimal BUGS, they need to know the specific characteristics of green spaces that elicit human health benefits. Elucidating the role of the environmental microbiome in GSHB would provide both an impetus for creating and a tool for assessing these urban green spaces. If governments and urban developers can be assured that green space of any size can be of high quality, they may be more willing to include a biodiverse refuge as part of their development.

China

The rapid urbanization of China has resulted in major public health problems. Fine particulate air pollution

Table 1. Concerns expressed by public health professionals from Australia, China, India, and the UK over the use of biodiverse urban parks to improve public health and proposed solutions for these concerns

Public health concern or implementation barrier	*Proposed solutions*
Lack of evidence connecting environmental microbiomes and GSHB	Undertake international, interdisciplinary studies such as those proposed here
Increasing pressure on urban green spaces	Create small-scale, microbially diverse green space hotspots
Funding the production of BUGS	Implement financial incentives to include green space in all new urban development projects (eg as is done in South Australia)
Lack of global data on environmental and human microbial communities	Create an open-access database into which all geographically referenced green space and human microbiome data are deposited
Lack of public engagement	Create technological applications that engage people with green spaces, educate them about how to realize potential health benefits, and return health and environment data to researchers
Disconnect between researchers, policy makers, and urban designers	Publish data and papers in open sources, engage media, and partner with local governments, health organizations, and public and private development industries
Lack of knowledge about how local culture, climate, and genetics influence the way people engage with and benefit from BUGS	Conduct studies around the world and explicitly measure differences attributable to culture, climate, and genetics

currently threatens the health of over 942 million Chinese citizens (He *et al.* 2016; Figure 3c), and the incidence of obesity is increasing among many urban residents, along with stress-related mental and emotional illnesses and less regular exercise (Gong *et al.* 2012). With more urban residents than any other country in the world, China has the most to gain from any positive health impacts of BUGS.

The Chinese government recognizes the considerable economic and public health benefits to be gained from green spaces and has implemented the biggest programs in the world to maintain and restore healthy ecosystems (Liu *et al.* 2008). Specifically, China has invested substantial effort into understanding the role of green spaces in (1) removing CO_2, dust, pollutants, bacteria, and viruses from air and water (ie phytoremediation), and (2) reducing urban heat island effects (MA 2005).

Local and federal Chinese policies directly affect the health of approximately 20% of the global population; therefore, improving the effectiveness and accessibility of BUGS in Chinese cities could have a major positive impact on the global public health burden.

However, Chinese officials are concerned about the shortage of local GSHB studies and question whether studies conducted in the US, Australia, or the UK are equally applicable in China. Furthermore, the absence of baseline environmental and human microbiome data and the challenge of engaging the public in studies that are potentially extensive, invasive, or elaborate may limit the ability to conduct rigorous GSHB studies in China. Finally, if local GSHB studies reveal the importance of BUGS in improving health outcomes, then the disconnect between public health researchers, politicians, and private developers could complicate the implementation of any scheme to increase the number of BUGS.

B Alger

Figure 2. *City parks, such as (a) this "mini park" in Hobart, Australia, (b) Hyde Park in London, UK, and (c) Xujiahui Park in Shanghai, China, provide some social and recreational opportunities, but without biodiversity are unlikely to provide maximum health benefits to visitors.*

India

As one of the world's most rapidly urbanizing countries, India is expected to add 418 million people to its urban population by 2050 through migration and growth (World Bank 2015). Similar to that in China, urban expansion in India has led to increased pollution and a rising number of urban poor. Developing strategies for cities to reduce pollution, social inequalities, and urban-associated chronic diseases will be a major challenge in India's future (Kapadia 2010).

The Indian government's approval of the National Biodiversity Action Plan (Government of India, Ministry of Environment and Forests 2008) indicates federal support for the conservation of biodiversity and a recognition of the role of urban green spaces in providing ecosystem services (including social and recreational benefits) and preserving biodiversity. Yet, in practice, city development projects often eliminate existing urban green spaces to accommodate the increasing population (Figure 3, a and b).

M Breed

B Alger

Figure 3. *Within existing cities, biodiverse wetlands and other "natural" green spaces, such as those in Delhi, India (a), are increasingly being converted into lands for new buildings with greatly diminished vegetation, as shown here in Gurgaon, India (b). In developing nations, sparse remnant vegetation, as seen in Shanghai, China (c), is insufficient to counteract rising levels of pollution.*

Economic assessments that incorporate the potential long-term health benefits of BUGS would play an important role in the urban development decision-making process. This is particularly important in India, given the potential for BUGS to reduce health-related inequalities among socioeconomic groups (Mitchell and Popham 2008) and impart the greatest proportion of health benefits to the urban poor (Rook *et al.* 2014). Furthermore, the majority of GSHB studies have been conducted in Europe and North America, but local culture and climate influence the way that people interact with green spaces and presumably the way that green spaces affect human microbiomes and health. Until local examinations of how people interact with green spaces and how this interaction affects immunological or other health metrics are conducted in India, it will be difficult to optimize India's urban green spaces for maximum health and social benefits.

UK

Much of the existing GSHB research has been conducted in the UK and US, and UK public health authorities are attempting to incorporate these research findings into policy. For example, the health benefits of green space are officially recognized by many UK organizations, including Public Health England, the King's Fund, UK Faculty of Public Health, Forestry Commission Scotland, and the Parliamentary Office of Science and Technology.

Despite this recognition (eg Figure 2b), the role of microbiomes has yet to be incorporated into public health strategies. Natural England, the UK government's advisor for the natural environment, does identify microbiomes as being "an important health component of green space", but suggests that the research is neither conclusive nor currently being applied in the UK. From the UK government perspective, the main benefit of urban green space is how it improves urban livability as well as the mental and physical health and longevity of urbanites. The under-recognition of the potential for BUGS to mitigate three medical conditions (Rook 2013; Kuo 2015) – namely cancer, inflammatory disease, and mental illness, which represent important contributors to the public health burden in the UK – is a major concern.

As the birthplace of the "hygiene", "old friends", and "biodiversity" hypotheses (Strachan 1989; Rook 2009, 2013; Rook *et al.* 2013), the UK is well poised to lead BUGS-related public health initiatives. The recent decentralization of the UK health care system has reinvigorated the GSHB discussion, and many organizations have released visions of how green space can be incorporated into local, place-based health schemes. Nevertheless, until biodiversity and microbiomes are explicitly recognized as important components of those green spaces, and until best practices in BUGS design and implementation have been established, the achieved GSHB may fall short of their full potential.

Knowledge gaps and an interdisciplinary call to action

These international perspectives highlight not only the variation in global recognition of GSHB but also selected barriers to using BUGS for public health benefit (Table 1). Overcoming these barriers would lead to a greater understanding of human and environmental microbiomes worldwide, and an understanding of how to design green spaces that provide maximum health benefits. These perspectives also underscore the potential for BUGS to alleviate chronic diseases arising from immune dysregulation, especially in urbanizing nations such as China and India.

Despite the relative infancy of the study of microbiomes, it is clear that they have broad and far-reaching impacts on human health and are proving to be crucial in a variety of settings from mental health to cancer growth to how patients respond to medicines (Honda and Littman 2016; Lowry *et al.* 2016). GSHB are well established and recognized in most countries but researchers have yet to explore the relationship between urban green space microbiomes

Panel 1. Suggested studies and techniques to rapidly advance current understanding of the influence of environmental microbiomes on human microbiomes and their connections to human health

Studies

(1) Perform global, comparative examinations of microbiomes within and among green spaces to link microbiomes to environmental features, including macro-biodiversity (plant and animal communities)
(2) Pair microbiome sampling with epidemiological studies to detect how local microbial biodiversity relates to human health metrics
(3) Conduct economic analyses of the health gains and reduced burden on the health budget provided by BUGS to compare to the cost of conserving, restoring, and creating BUGS
(4) Expose captive animals (eg mice) to microbial communities collected from the environment and monitor immune function and health metrics to identify critical microbes/characteristics of beneficial microbial communities
(5) Sample human microbiomes (skin, airway, gut, etc) and then pair with surveys and genetic data to identify:
   (a) How environmental microbiomes in urban green spaces seed and alter different human microbiomes
   (b) The behaviors/types of interaction with green space that facilitate exposure to and transfer of microbes
   (c) The frequency and duration of interaction with BUGS that is needed to modify human microbiomes
   (d) How genetics alter the way an individual responds to environmental microbiomes
   (e) Changes to microbiome and immune parameters before and after exposure to BUGS

Techniques

(1) Use open-source microbiome databases, crowdsource microbiome samples, and develop and implement technological interfaces (eg apps) to engage the public and provide location-specific information to pair with remotely sensed and directly collected datasets
(2) Conduct studies in different countries and at different latitudes to see how microbial communities differ, and how cultural and genetic differences influence green space interactions and health outcomes
(3) Translate research outcomes into practical recommendations so that those responsible for designing cities, and promoting health, can implement and deliver optimal BUGS

and human health. We urge the global community to undertake efforts to fill critical knowledge gaps (Figure 1), using proposed solutions and techniques (Table 1; Panel 1). Filling these gaps will require collaborations – among ecologists, immunologists, physicians, statisticians, microbiologists, epidemiologists, bioinformaticians, social scientists, and economists – that cross traditional departmental, institutional, and international boundaries. Likewise, urban planners, engineers, landscapers, and politicians need to incorporate any new findings into their work, and the greatest health gains will be realized if sociologists, marketing and communication experts, and the media then help motivate the public to engage with BUGS. It will also be the role of these international interdisciplinary research teams to generate the evidence base upon which politicians, economists, and government officials can build effective urban green space policy.

Conclusions

A multitude of GSHB studies has largely established that green space positively influences many dimensions of health (Figure 1), but the direction and scale of the impact varies by study. One potential explanation for these discrepancies is that the variation, elucidated by recent theoretical analyses, could be attributed to the unmeasured microbial diversity of the green spaces. Until there is an improved understanding of the contribution of this critical component of green space, scientists can neither rectify the conflicting findings of GSHB studies nor design urban green spaces that offer optimal health benefits.

The international perspectives presented here highlight a diversity of challenges to – and benefits of – using BUGS to improve global urban health. Systematic, interdisciplinary, international investigations are needed to demonstrate the ability of BUGS to provide the human microbiome with the microbial species and diversity to produce maximum health benefits. Here, we have identify critical studies, challenges, and solutions to elucidating the links between GSHB and the microbial diversity of BUGS (Table 1; Panel 1). If these studies are paired with strong collaborations among governments, researchers, and community groups, then this field could hold the potential to stem the increase in chronic diseases projected to follow the rapid urbanization trend worldwide.

Acknowledgements

We thank A Flies for feedback; the Environment Institute, University of Adelaide, for support; and B Alger and M Breed for pictures of parks in China and India (Figures 2 and 3).

References

Aronson MFJ, La Sorte FA, Nilon CH, *et al.* 2014. A global analysis of the impacts of urbanization on bird and plant diversity reveals key anthropogenic drivers. *P Roy Soc London B Biol Sci* **281**: 1–8.

Arrieta MC, Stiemsma LT, Amenyogbe N, *et al.* 2014. The intestinal microbiome in early life: health and disease. *Front Immunol* **5**: 427–44.

Bach JF. 2002. The effects of infection on susceptibility to autoimmune and allergic diseases. *N Engl J Med* **347**: 911–20.

David LA, Maurice CF, Carmody RN, *et al*. 2014. Diet rapidly and reproducibly alters the human gut microbiome. *Nature* **505**: 559–63.

Gong P, Liang S, Carlton EJ, *et al*. 2012. Urbanisation and health in China. *Lancet* **379**: 843–52.

Government of India, Ministry of Environment and Forests. 2008. National Biodiversity Action Plan (NBAP). New Delhi, India. http://nbaindia.org/uploaded/Biodiversityindia/NBAP.pdf. Viewed 11 Sep 2017.

Haahtela T, Holgate S, Pawankar R, *et al*. 2013. The biodiversity hypothesis and allergic disease: World Allergy Organization position statement. *World Allergy Organ J* **6**: 3.

Hanski I, von Hertzen L, Fyhrquist N, *et al*. 2012. Environmental biodiversity, human microbiota, and allergy are interrelated. *P Natl Acad Sci USA* **109**: 8334–39.

He C, Han L, and Zhang RQ. 2016. More than 500 million Chinese urban residents (14% of the global urban population) are imperiled by fine particulate hazard. *Environ Pollut* **218**: 558–62.

Honda K and Littman DR. 2016. The microbiota in adaptive immune homeostasis and disease. *Nature* **535**: 75–84.

Kapadia K. 2010. Sustainable urbanization: India's challenge in the 21st century. In: Teng JG (Ed). Proceedings of the First International Conference on Sustainable Urbanization; 15–17 Dec 2010; Hong Kong, China: Hong Kong Polytechnic University.

Kuo M. 2015. How might contact with nature promote human health? Promising mechanisms and a possible central pathway. *Front Psychol* **6**: 1093.

Lewis SA. 2000. Animals and allergy. *Clin Exp Allergy* **30**: 153–57.

Li Q. 2010. Effect of forest bathing trips on human immune function. *Environ Health Prev Med* **15**: 9–17.

Liu J, Li S, Ouyang Z, *et al*. 2008. Ecological and socioeconomic effects of China's policies for ecosystem services. *P Natl Acad Sci USA* **105**: 9477–82.

Lowry CA, Smith DG, Siebler PH, *et al*. 2016. The microbiota, immunoregulation, and mental health: implications for public health. *Curr Environ Heal Reports* **3**: 270–86.

MA (Millennium Ecosystem Assessment). 2005. Ecosystems and human well-being: synthesis. Washington, DC: Island Press.

Mitchell R and Popham F. 2008. Effect of exposure to natural environment on health inequalities: an observational population study. *Lancet* **372**: 1655–60.

Radon K, Windstetter D, Poluda AL, *et al*. 2007. Contact with farm animals in early life and juvenile inflammatory bowel disease: a case-control study. *Pediatrics* **120**: 354–61.

Rook GAW. 2009. Review series on helminths, immune modulation and the hygiene hypothesis: the broader implications of the hygiene hypothesis. *Immunology* **126**: 3–11.

Rook GAW. 2012. Hygiene hypothesis and autoimmune diseases. *Clin Rev Allergy Immunol* **42**: 5–15.

Rook GAW. 2013. Regulation of the immune system by biodiversity from the natural environment: an ecosystem service essential to health. *P Natl Acad Sci USA* **110**: 18360–67.

Rook GAW, Lowry CA, and Raison CL. 2013. Microbial "old friends", immunoregulation and stress resilience. *Evol Med Public Health* **2013**: 46–64.

Rook GAW, Raison CL, and Lowry CA. 2014. Microbial "old friends", immunoregulation and socioeconomic status. *Clin Exp Immunol* **177**: 1–12.

Schnorr SL, Candela M, Rampelli S, *et al*. 2014. Gut microbiome of the Hadza hunter-gatherers. *Nat Commun* **5**: 1262–67.

Strachan DP. 1989. Hay fever, hygiene, and household size. *BMJ Brit Med J* **299**: 1259–60.

von Hertzen L, Beutler B, Bienenstock J, *et al*. 2015. Helsinki alert of biodiversity and health. *Ann Med* **47**: 1–8.

von Hertzen L, Hanski I, and Haahtela T. 2011. Natural immunity: biodiversity loss and inflammatory diseases are two global megatrends that might be related. *EMBO Rep* **12**: 1089–93.

WHO (World Health Organization) and CBD (Convention on Biological Diversity). 2015. Connecting global priorities: biodiversity and human health. A state of knowledge review. Geneva, Switzerland: WHO Press.

World Bank. 2015. Urban population data. http://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS. Viewed 25 Nov 2016.

Supporting Information

Additional, web-only material may be found in the online version of this article at http://onlinelibrary.wiley.com/doi/10.1002/fee.1630/suppinfo

[6]*State Key Laboratory of Infectious Disease Prevention and Control, CCID, National Institute for Communicable Disease Control and Prevention, China CDC, Beijing, China;* [7]*World Health Organization Collaboration Centre for Vector Surveillance and Management, Beijing, China;* [8]*Children's Health and Environment Program, Children's Health Research Centre, University of Queensland, Brisbane, Australia;* [9]*Health Department, Government of South Australia, Adelaide, Australia*

