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Urban green spaces and health

A review of evidence

ABSTRACT

This report summarizes the available evidence of beneficial effects of urban green spaces, such as improved mental health, reduced cardiovascular morbidity and mortality, obesity and risk of type 2 diabetes, and improved pregnancy outcomes. Mechanisms leading to these health benefits include psychological relaxation and stress alleviation, increased physical activity, reduced exposure to air pollutants, noise and excess heat. Characteristics of urban green spaces that are associated with specific mechanisms leading to health benefits, and measures or indicators of green space availability, accessibility and use that have been used in previous surveys are discussed from the perspective of their public health relevance and applicability for monitoring progress towards goals set in international commitments, such as the Parma Declaration in the WHO European Region and the global Sustainable Development Goals. The report also presents a suggested indicator of accessibility of green spaces with examples of its application in three European cities and a detailed methodological tool kit for GIS analysis of land use and population data.

Keywords

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List of abbreviations

ADHD	Attention Deficit Hyperactivity Disorder
BME (groups)	black and minority ethnic (groups)
CORINE	Coordination of Information on the Environment
EEA	European Environment Agency
EEG	Electroencephalography
EU	European Union
GIS	Geographic Information System
GPS	Global Positioning System
NDVI	Normalized Difference Vegetation Index
UV (light)	ultraviolet (light)
US EPA	United States Environmental Protection Agency
WHO	World Health Organization

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1. INTRODUCTION

There is a recent revival of interest in the importance of green space to support healthy living in urban areas. Links between green space and health have been recognized throughout history, and were one of the driving forces behind the urban parks movement of the 19th century in Europe and North America (Schuyler, 1988).

However, many of the mechanisms behind such links were poorly understood or lacked rigorous scientific evidence. In the 21st century, new research techniques provide opportunities to study the mechanisms behind associations between green space and health with increasing sophistication and help satisfy contemporary scientific standards of evidence demanded to inform policy and practice. This refined understanding of the health promotion potential of urban green spaces can contribute to addressing major public health issues related to noncommunicable diseases. Across Europe and beyond, preventable noncommunicable diseases, such as mental illness, obesity, cardiovascular diseases, type 2 diabetes and cancer, remain major factors not only affecting health and well-being, but also driving up the cost of health care and reducing the productivity of the workforce. Many such illnesses are linked to chronic stress and lifestyle factors, such as insufficient physical activity (Shortt et al., 2014). Urban green spaces, as part of a wider environmental context, have the potential to help address problems 'upstream', in a preventative way – considered a more efficient approach than simply dealing with the 'downstream' consequences of ill health (Morris et al., 2006).

At the Fifth Ministerial Conference on Environment and Health in Parma, Italy (2010), the Member States of the WHO European Region made a commitment "…to provide each child by 2020 with access to healthy and safe environments and settings of daily life in which they can walk and cycle to kindergartens and schools, and to green spaces in which to play and undertake physical activity" (WHO, 2010b). Improving access to green spaces in cities is also included in the United Nations Sustainable Development Goal 11.7, which aims to achieve the following: "By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities" (United Nations Department of Economic and Social Affairs, 2014). Finally, the WHO Action Plan for the implementation of the European Strategy for the Prevention and Control of Noncommunicable Diseases in 2012−2016 includes a call to create health-supporting urban environments (WHO, 2012).

Previous WHO reports have already contributed evidence and guidance on access to green space in relation to public health benefits. A WHO report on urban planning, environment and health published in 2010 states that green spaces can positively affect physical activity, social and psychological well-being, improve air quality and reduce exposure to noise; however, they can also be associated with an increased risk of injury due to increased recreational and sport-related use (WHO, 2010d). Another WHO report evaluated the effects of green spaces on physical activity and their potential to reduce public health inequalities. It states that "… access to public open space and green areas with appropriate recreation facilities for all age groups is needed to support active recreation", but recognizes that multidisciplinary and intersectoral interventions may be needed to support disadvantaged groups where physical activity levels are lowest (WHO, 2013).

Recent studies have provided evidence of multiple benefits from urban green space, through various mechanisms, and with potentially differential impacts in various populations. Epidemiological studies have used a multitude of approaches to measure the effects of urban green space availability and accessibility on the health outcomes of study participants. Given the potential of urban green spaces to act as settings for health promotion it is therefore necessary to summarize the existing evidence identifying, where possible, the underlying mechanisms contributing to both the negative and positive health outcomes of urban green space. There is also a need to summarize existing understandings of the characteristics of urban green space that may differentially be associated with

health outcomes, and to understand how different populations may be affected and benefit in different ways.

This report offers a review of the existing evidence on the health effects of green space in urban areas alongside a summary of health-relevant measures of green space availability, accessibility and usage. The report also presents a toolkit outlining an example of a Geographic Information System (GIS)-based approach to measuring urban green space that WHO has recently applied in three European cities (Annerstedt van den Bosch et al., 2016). The review is not systematic but, rather, an overview of previous WHO reports and other previously published reviews as well as selected recent research publications. The main objectives of this report are to inform public health specialists and policy-makers on the benefits of providing urban residents with green space access, and to provide cities with systematic approaches to quantifying and monitoring their green space access. In doing so this report advocates the implementation and evaluation of targeted, evidence-based green space interventions for the health promotion of urban residents.

2. EVIDENCE ON HEALTH BENEFITS OF URBAN GREEN SPACES

This section summarizes the evidence of pathways to health and health benefits of urban green space focusing particularly on research published over the last 10 years. Potential mechanisms by which green space may affect public health are discussed first, followed by specific health benefits demonstrated by epidemiological studies and, finally, potential detrimental effects.

2.1 Definitions of urban green space

Currently, there is no universally accepted definition of urban green space, with regard to its health and well-being impacts. Urban green spaces may include places with 'natural surfaces' or 'natural settings', but may also include specific types of urban greenery, such as street trees, and may also include 'blue space' which represents water elements ranging from ponds to coastal zones. Typical green spaces in urban areas are public parks; other definitions may also include private gardens, woodlands, children's play areas, non-amenity areas (such as roadside verges), riverside footpaths, beaches, and so on. The definitions are nuanced and context-specific. For example, they can depend on particular environment-health pathways under consideration. Examples of green space definitions are presented in Appendix 1.

The following review of health benefits as well as discussion of green space measures and indicators in Section 3 of the report summarize all available evidence and experience based on various definitions of urban green space, reflecting varying ways in which it is described and defined in different studies.

Consideration of urban green space in different research usually includes public parks and gardens, but may or may not also include a range of other areas, such as other public open space, street trees, sports pitches and recreational facilities such as golf courses, private and semi-private gardens and other residential open space, roof gardens, urban agriculture, commercial forests, vegetated waste land, indeed any place where there is a natural surface or where trees are growing.

The most common definition of urban green space that has been used in studies in Europe is based on the definition from the European Urban Atlas (European Union, 2011). The Green Urban Areas as defined by Urban Atlas code 14100 include public green areas used predominantly for recreation such as gardens, zoos, parks, and suburban natural areas and forests, or green areas bordered by urban areas that are managed or used for recreational purposes. In policy terms, it is important to focus on urban green space that is open to the public particularly when considering universal green space access for all urban residents, regardless of socioeconomic circumstances. However, where relevant the overview includes studies that have used wider or more inclusive definitions of urban green space.

While the Urban Atlas excludes bodies of water from the definition of Green Urban Areas, we recognize that water is often part of urban green space and that the water edge, whether, for example, along a river or lake, a sea beach or a cliff, is often an important and attractive feature for people to use and enjoy. For this reason, we might consider the working definition for urban green space used in this overview to include 'green/blue' space which may be of benefit in its entirety, and where the riparian zone and access to water may be particularly valued and used by urban dwellers. This overview does not, however, include studies that are explicitly focused on the health benefits of water-based sports and recreation.

2.2 Pathways linking urban green space to improved health and well-being

2.2.1 Overview of pathways to health

The mechanisms underlying links between green space access and health are likely to be complex and interacting. Access to green space may produce health benefits through various pathways (mechanisms leading to health effects), some of which may have a synergistic effect. Various models

have been proposed to explain the observed relationship between green space and health. Hartig et al. (2014) suggested four principal and interacting pathways through which nature or green space may contribute to health: improved air quality, enhanced physical activity, stress reduction and greater social cohesion. Lachowycz & Jones (2013) emphasized physical activity, engagement with nature and relaxation, and social activities and interactions as major pathways to health. Villanueva et al. (2015) proposed a model that emphasizes respiratory health and resilience to heat-related illness, social capital and cohesion, and physical activity. Kuo (2015) suggests a central role for enhanced immune functioning as a pathway between nature and health, recognizing that there may be multiple pathways, some of which may interact and offer both direct and indirect benefits. Hartig et al. (2014) summarized the existing strong evidence for restorative psychological effects from interaction with green space or natural environments.

2.2.2 Improved relaxation and restoration

It has been recognized for centuries that contact with nature can be restorative and evidence of mental health benefits from having contact with nature and green spaces is well documented (Hartig, 2007; Hartig et al., 1991). There are two main theories that attempt to explain this:

a) *Psycho-physiological stress reduction theory* proposes that contact with nature (e.g. views of natural settings) can have a positive effect for those with high levels of stress, by shifting them to a more positive emotional state (Ulrich, 1983; Ulrich et al., 1991). As people are innately predisposed to find non-threatening natural stimuli relaxing, exposure to these stimuli triggers a parasympathetic nervous system response leading to feelings of enhanced well-being and relaxation.

b) *Attention Restoration Theory* suggests that involuntary attention given to interesting and rich stimuli in natural settings helps to improve performance in cognitively demanding tasks (Kaplan and Kaplan, 1989; Kaplan, 1995; Kaplan, 2001; Kaplan and Kaplan, 2011). People have two types of attention: directed attention, which requires effort and, therefore, is a limited resource, and fascination or effortless involuntary attention. Working on specific tasks requiring direct attention depletes this limited resource while involuntary attention, which is facilitated in natural environments, restores it and, therefore, improves cognitive performance.

Both are psycho-evolutionary theories, based on the biophilia hypothesis, which postulates that humans have an innate need to affiliate with the natural environment within which they have evolved (Wilson, 1984). Both theories suggest that interaction with the natural environment serve a restorative function but through different mechanisms (reviewed by Clatworthy et al., 2013).

Support for these theories has been provided by studies that demonstrate restorative physiological responses associated with viewing or being in green space, including reduced blood pressure (Hartig et al., 2003, Ottosson & Grahn, 2005, Ulrich et al., 1991), heart rate (Ottosson & Grahn, 2005, Ulrich et al., 1991), skin conductance and muscle tension (Ulrich et al., 1991). Evidence of psychoneuroendocrine responses to woodland environments are based on observed associations with lower concentrations of cortisol, lower pulse rate, lower blood pressure, greater parasympathetic nerve activity and lower sympathetic nerve activity when compared to city environments (Lee et al., 2011; Park et al., 2007).

Hartig et al. (2014) noted that “substantial evidence speaks to the potential benefits of contact with nature for avoiding health problems traceable to chronic stress and attentional fatigue”, but also pointed out that most previously conducted studies demonstrated only short-term restorative benefits of an episode of experiencing nature. For example, a study in the United Kingdom used wearable electroencephalography (EEG) devices to demonstrate the effects of a short walk in a green space on brain activity that might be associated with enhanced relaxation and restoration (Aspinall et al., 2015). It was also shown that walking in natural environments produces stronger short-term cognitive benefits than walking in the residential urban environment (Gidlow et al., 2016a). Using the diurnal cortisol pattern as a biomarker of chronic stress is an innovative approach that was applied in

the United Kingdom to demonstrate that exposure to green space reduces chronic stress in adults living in deprived urban neighbourhoods (Roe et al., 2013, Ward Thompson et al., 2012; Beil & Hanes 2013). Similar relationships between green space and stress reduction have been shown using hair cortisol as a biomarker of chronic stress (Honold et al., 2016; Gidlow et al., 2016b). Cortisol measures have also demonstrated the stress reducing effects of gardening (van den Berg & Custer, 2011) suggesting that such activities in green space may be particularly restorative. It has also been demonstrated that exposure to green spaces reduces neural activity in the subgenual prefrontal cortex and alleviates depression symptoms (Bratman et al., 2015).

2.2.3 Improved social capital

There is a well-known protective effect of social relationships on health and well-being, while social isolation is a known predictor of morbidity and mortality (Nieminen et al., 2010; Pantell et al., 2013; Yang et al, 2016). Green space can play an important role in fostering social interactions and promoting a sense of community (Kim and Kaplan, 2004). In a recent study in the Netherlands, de Vries et al. (2013) found an association between the quantity and, even more strongly, the quality of streetscape greenery and perceived social cohesion at the neighbourhood scale. In that study, social cohesion was defined as a sense of community, with a focus on trust, shared norms and values, positive and friendly relationships, and feelings of being accepted and belonging. The researchers developed an indicator of social cohesion based on questionnaire data. Conversely, a shortage of green space in the environment has been linked to feelings of loneliness and lack of social support (Maas et al., 2009a, Ward Thompson et al., 2016). Various types of urban green space have been shown to facilitate social networking and promote social inclusion in children and adolescents (Seeland et al., 2009).

Neuroscience has provided evidence that place constitutes a distinct dimension in neuronal processing and so ´sense of place´ and ´place identity´, in which the social and natural environment have particular roles, are important dimensions for human health (Lengen & Kistemann, 2012). Hartig et al. (2014) underlined that the relationships between social well-being and green space are complex and, while observational research may reveal associations, the underlying mechanisms are not easy to explore. Social well-being may not be beneficially affected by green and open space that is perceived as unsafe or where people engage in antisocial behaviour, although these problems can be addressed by proper management and maintenance. There is also some evidence that provision of new green spaces in disadvantaged neighbourhoods (e.g. greening of vacant lots) can reduce crime (Branas et al., 2011; Chong et al., 2013).

2.2.4 Improved functioning of the immune system

Japanese studies have demonstrated associations between visiting forests and beneficial immune responses, including expression of anti-cancer proteins (Li et al., 2008). This suggests that immune systems may benefit from relaxation provided by the natural environment or through contact with certain physical or chemical factors in the green space. It has been shown that children with the highest exposure to specific allergens and bacteria during their first year were least likely to have recurrent wheeze and allergic sensitization (Lynch et al., 2014). Another suggested immunological pathway is through exposure to diverse microorganisms in the natural environments (Rook, 2013), which can play an immunoregulatory role. Kuo (2015) suggested a central role for enhanced immune functioning in the pathway between nature and health.

2.2.5 Enhanced physical activity, improved fitness and reduced obesity

Physical inactivity is identified as the fourth leading risk factor for global mortality (WHO, 2010a). Physical inactivity is becoming increasingly common in many countries with major implications for the prevalence of noncommunicable diseases and the general health of the population worldwide (WHO, 2012). Several environmental factors are recognized as contributing to physical inactivity in

cities, such as high traffic volumes and lack of parks and footpaths. Hartig et al. (2014) found some evidence for an association between green space and levels of physical activity, suggesting that the relationship may vary considerably between population subgroups; they underline how walking for recreation may be supported by green environments in a different way than walking as a means of transport.

Several studies in various countries have demonstrated that recreational walking, increased physical activity and reduced sedentary time were associated with access to, and use of, green spaces in working age adults, children and senior citizens (Wendel-Vos et al., 2004; Epstein et al., 2006; Kaczynski & Henderson, 2007; Kaczynski et al., 2008; Sugiyama & Ward Thompson, 2008; Sugiyama et al., 2009; Cochrane et al., 2009; Astell-Burt et al., 2013; Schipperijn et al., 2013; Lachowycz and Jones, 2014; Sugiyama et al., 2014; Gardsjord et al., 2014; James et al., 2015).

Almanza et al. (2012) used satellite images coupled with Global Positioning System (GPS) and accelerometer data from children in the United States to demonstrate that exposure to green space measured by Normalized Difference Vegetation Index (NDVI), which reflects the light-absorbing capacity of vegetation derived from satellite data, was positively associated with moderate to vigorous physical activity (MVPA).

Björk et al. (2008) and De Jong et al. (2012) found a positive association between high quality green spaces in the neighbourhood and higher levels of physical activity, as well as improved self-assessed health. High quality green space was defined as having a comparatively high number of recreational attributes, out of a total of five assessed by experts, including qualities associated with historical and cultural associations, spaciousness, richness of natural species, peaceful qualities and wildness. In a United Kingdom study of children aged 10-11 years, Lachowycz et al. (2012) showed that time spent in green space contributed over a third of all outdoor MVPA occurring during weekday evenings, over 40% on Saturdays and almost 60% on Sundays. Furthermore, links between green space use and MVPA were consistent in all seasons. In a Spanish study, Dadvand et al. (2014a) found that living in greener residential areas and proximity to forests was associated with less sedentary time and reduced risks of children being overweight or obese.

One way in which green space may be linked to health is through the enhanced benefits of physical activity *in* green or natural places, as opposed to other contexts. 'Green exercise', defined as physical activity undertaken in green or natural environments (Barton & Pretty, 2010), has been suggested as being more beneficial than other types of exercise (Marselle et al., 2013). For example, running in a park is associated with a more restorative experience when compared to the same exercise in an urban environment (Bodin and Hartig, 2003). Barton & Pretty's (2010) analysis of ten United Kingdom studies showed multiple mental health benefits from physical activity in green environments. Mitchell's (2013) study of the Scottish population showed an association between physical activity in natural environments and reduced risk of poor mental health, while activity in other types of environment was not linked to the same health benefit.

Interest in associations between green space and physical activity has also focused on behaviour change, with certain green spaces potentially encouraging greater levels of physical activity. In an Australian context, Sugiyama et al. (2013) found that the presence of and proximity to neighbourhood green spaces helps to maintain recreational walking over time.

Physical activity has been shown to improve cardiovascular health, mental health, neurocognitive development, and general well-being and to prevent obesity, cancer, and osteoporosis (Owen et al., 2010). Providing attractive urban green space may encourage people to spend more time outdoors and facilitate physical activity (Bedimo-Rung et al., 2005). In particular, many older people find it very difficult to maintain moderate levels of physical activity; therefore, providing green spaces that encourage older people to be active, even if it is only at a light level, is important for public health. The quality of the urban green space and its proper maintenance may be important factors in green space usage by older adults (Aspinall et al., 2010). Sugiyama & Ward Thompson (2008) demonstrated

an association between the quality of neighbourhood open space and increased walking in older people in the United Kingdom. For people with mental illness living in urban areas, physical activity in green space may be particularly beneficial (Roe and Aspinall, 2011). Other populations or subgroups may benefit, in a similar way, from green space that makes outdoor activity enjoyable and easy, hence encouraging less sedentary lifestyles.

A systematic review of 60 studies from the United States, Canada, Australia, New Zealand and Europe on the relationships between green spaces and obesity indicators found that the majority (68%) of papers showed that green space is associated with reduced obesity; the relationships could be modified by age and socioeconomic status (Lachowycz & Jones, 2011).

There is some evidence that using green space for growing food may influence physical activity, social well-being and encourage a healthy diet, thereby reducing obesity. A pilot intervention study using community gardening and education in nutrition in the United States found that obese and overweight children had improved their Body Mass Index status by the end of the seven-week-long programme (Castro et al., 2013).

2.2.6 Anthropogenic noise buffering and production of natural sounds

Noise pollution is a major and increasing threat to human health, due to continuing urbanization, rising traffic volumes, industrial activities, and a decreasing availability of quiet places in cities. The range of disease burden from noise pollution is estimated at 1.0 – 1.6 million Disability Adjusted Life Years in the European Region (WHO, 2011). Evidence suggests that a well-designed urban green space can buffer the noise, or the negative perception of noise, emanating from non-natural sources, such as traffic, and provide relief from city noise (González-Oreja et al., 2010; Irvine et al., 2009).

Vegetation has been considered as a means to reduce outdoor noise pollution, mainly in areas with high volumes of traffic. A study in Uttar Pradesh, India (Pathak et al., 2008) showed significant reductions in traffic noise pollution from vegetation belts of 1.5 – 3 m width and a similar height range, with greater noise reduction as noise frequency increased (peak attenuation occurred between 2.5–5 KHz). This reinforces findings from a number of earlier studies in Europe and North America, indicating that a combination of land form and vegetation were most effective in attenuating traffic noise. For example, Huddart (1990) in the United Kingdom showed the effectiveness of 10 m wide tree belts. However, Yang et al. (2011) undertook experiments using EEG and showed that over half their participants overrated the ability of roadside vegetation to attenuate noise. The researchers suggest that, because almost all participants believed that a vegetation barrier could reduce noise, the plants affect people's emotional processing and that there is therefore a psychological mechanism at work in perceived noise reduction, and especially in the level of noise attenuation that vegetation effects. In a Swedish study, Gidlöf-Gunnarsson & Öhrström (2010) also showed that vegetated courtyards moderate the negative effects of traffic noise.

A different but not unrelated effect of green and blue space in relation to noise perception is the effect of other natural noises in masking noise pollution such as from traffic. In a Belgian study, Coensel et al. (2011) explored perceived loudness, pleasantness, and eventfulness of stimuli that combined road traffic noise with fountain or bird sound at different sound levels. Adding a fountain sound reduced the perceived loudness of road traffic noise only if the latter had low temporal variability. Conversely, adding bird sound significantly enhanced soundscape pleasantness and eventfulness, more so than for the fountain sound. The authors conclude that soundscape quality is influenced heavily by the meaning associated with the different sounds that are heard. Galbrun & Ali (2013) subsequently explored the perception of water sounds to mitigate road traffic noise and found that, to be effective, water sounds should be similar to, or not less than 3 dB below, the road traffic noise level (confirming previous research), and that stream sounds tend to be preferred to fountain sounds, which are in turn preferred to waterfall sounds.

2.2.7 Reduced exposure to air pollution

Evidence of mitigating effects of urban green space on exposure to anthropogenic air pollutants in cities has been reviewed by Bowler et al. (2010a). Vegetation (trees, shrubs, herbs and grass) can dampen the impacts of road traffic and industries and improve air quality in urban residential areas providing benefits for public health. Urban residents in different countries (Portugal and France) have recognized the role of green space in improving perception of air quality (Madureira et al., 2015). Trees and other vegetation can decrease levels of air pollutants and reduce atmospheric carbon dioxide through carbon storage and sequestration (Liu and Li, 2012, Nowak et al., 2006, Vailshery et al., 2013, Baró et al., 2014, Nowak et al., 2013, Calfapietra et al., 2016, Manes et al., 2012). Therefore, green spaces provide indirect health benefits in addition to those associated with direct contacts with greenery (Dadvand et al., 2012a). (Potential detrimental effects of green spaces due to trapping air pollutants are discussed in Section 2.4 below.)

2.2.8 Reduction of the urban heat island effect

Heat related morbidity in cities is a major public health concern (WHO and WMO, 2015). The Urban Heat Island effect can be a serious health hazard during heat waves and extreme heat events. It arises due to replacement of vegetation with impervious heat-absorbing surfaces in urban areas. Exposure to excessive heat is linked to increased morbidity and mortality, especially in vulnerable subpopulations, such as the elderly (Smargiassi et al., 2009; Basagaña et al., 2011). A systematic review and meta-analysis of literature on how urban parks affect the air temperature in urban areas showed an average cooling effect of approximately 1^{o} C (Bowler et al., 2010a). The study also suggested that parks may mitigate urban heat in wider surrounding urban areas, with data suggesting an effect up to 1 km from the park boundary. The inclusion of water bodies within the green space may offer greater cooling effects (Völker et al., 2013). Another review indicated that urban greenery, including parks, street trees and green roofs, mitigate Urban Heat Island effects (Shisegar 2014). In the United States, Harlan et al. (2006) showed that densely populated areas, sparse vegetation, and low levels of open space in the neighbourhood were significantly linked to higher temperatures and urban heat islands in Phoenix, Arizona. During warmer weather, trees can provide shade and reduce the demand for air conditioning and, especially, in warmer countries, they can provide comfortable outdoor settings and allow people to avoid heat stress (Lafortezza et al., 2009). Jenerette et al. (2011) emphasized the role that vegetation and green space play in reducing surface temperature in Phoenix and how more equitable access to urban green areas and vegetation would reduce income-associated inequality in exposure to extreme heat and protect vulnerable groups, such as elderly individuals. In cooler climates, trees can also provide shelter from wind and thereby reduce heating demand in the cold season.

2.2.9 Enhanced pro-environmental behaviour

Pro-environmental behaviour can be defined as “behaviour that consciously seeks to minimize the negative impact of one’s actions on the natural and built world” (Kollmuss & Agyeman, 2002). In the face of climate change, which is projected to have serious detrimental effects on health, an upstream approach to minimizing and mitigating its effects is to promote pro-environmental behaviour (Annerstedt van den Bosch & Depledge, 2015). The authors suggested that, as with many social behaviours, pro-environmental behaviour can be induced by external stimuli, particularly by experiencing natural environments. Recent research has supported this, showing that exposure to nature may increase cooperation and, when considering environmental problems as social dilemmas, sustainable intentions and behaviour (Zelenski et al., 2015). There is also evidence that childhood experiences in nature appear to enhance adult environmentalism (Wells and Lekies, 2006). If pro-environmental actions are widely adopted, people can contribute to substantially reducing carbon emissions (Dietz et al., 2009) thereby potentially preventing detrimental effects of climate change on health.

2.2.10 Optimized exposure to sunlight and improved sleep

If access to green space supports greater time spent outdoors among the population, it is likely to be accompanied by increased exposure to sunlight, which can have positive effects as well as negative effects (the latter are discussed in section 2.4). Humans get most of their vitamin D from exposure to sunlight, and optimum levels of vitamin D are important for overall health and well-being, especially bone density, so access to green space may contribute to better levels of vitamin D and associated health benefits (Gillie, 2005). This may be especially important for northern Europeans whose environment lacks high level sunlight for significant parts of the year, and for older people, since the ability to synthesise Vitamin D decreases with age. However, there is lack of studies looking at the role of green space and levels of vitamin D. De Rui et al. (2014) explored how different pastimes influenced the levels of Vitamin D in older people. The authors found that vitamin D levels were significantly higher in those who engaged in outdoor activities, rather than for those who did not. The levels were particularly high for those who cycled or partook in gardening.

Natural light also contains a spectrum of light wavelengths, some of which may be beneficial or detrimental. Access to sunlight brings the risk of exposure to dangerous levels of ultraviolet (UV) light, especially in southern hemisphere countries such as Australia, as reported in section 2.4. However, recent research also suggests that UV-induced release of nitric oxide from skin may have unexpected health benefits, including lowering the incidence of hypertension and cardiovascular disease (CVD) that is particularly associated with lower latitudes and winter months (Liu et al., 2014).

Light exposure, particularly to blue light, is also recognized as way to stimulate alertness and cognition, and to promote healthy sleep. Exposure to blue light is implicated in metabolism and circadian rhythms, where naturally occurring patterns of daylight support healthy circadian rhythms but exposure to blue light at inappropriate times (e.g. at night) may suppress the secretion of hormones that influence such rhythms. However, there is some evidence that the beneficial effect of natural light on cognition may diminish with age (Daneault et al., 2014).

Adequate sleep is crucial for good health, while sleep deprivation has been linked to adverse health outcomes, such as metabolic syndrome, cardiovascular morbidity and mortality, and neurocognitive disorders, such as dementia (Schmid et al., 2015; Kohansieh & Makaryus, 2015; Miller, 2015). An Australian study showed that those living in a greener neighbourhood had lower risk of insufficient sleep (less than six hours) (Astell-Burt et al., 2013). In the United States, Grigsby-Toussaint et al. (2015) found that access to natural environments reduced the prevalence of self-reported insufficient sleep in adults, especially men. Therefore, green space access may benefit health through increasing people's exposure to natural patterns of daylight, hence helping to maintain circadian rhythms.

2.3 Evidence of health benefits of green spaces

2.3.1 Improved mental health and cognitive function

Studies of green spaces and health have demonstrated stronger evidence for mental health benefits, and for stress reduction, compared with other potential pathways to health (reviewed by de Vries, 2010; Gascon et al., 2015). An Australian study has shown perceived neighbourhood greenness to be more strongly associated with mental health than with physical health (Sugiyama et al., 2008) while a study in Spain (Triguero-Mas et al., 2015) found that greater exposure to green space was linked to improved physical and mental health across all socioeconomic strata and genders. The associations were stronger for surrounding greenness (measured by NDVI) than for distance to green space. Further analysis demonstrated that this association was not mediated by physical activity. Moving to greener areas has been associated with mental health improvements in the United Kingdom (Alcock et al., 2014). Individuals living in urban areas with more green space have been shown to have a reduced level of stress and improved well-being compared to controls with poorer availability of green space (White et al., 2013a). A study in the United States found that higher levels of

neighbourhood greenery were linked to lower levels of depression, anxiety and stress (Beyer et al., 2014), while a German study found mental well-being in city dwellers to be particularly associated with blue space (Völker & Kistemann, 2015). In a longitudinal study, researchers in Sweden found a significant association between gained access to 'serene' green space and improved mental health in women (van den Bosch et al., 2015). A cross-sectional study in England linked the quality of, and access to, green space with reduced psychological distress (Pope et al., 2015). Another recent cross-sectional study in Lithuania demonstrated that, among individuals who regularly use parks, closer proximity of their home to the nearest park was associated with reduced odds of self-reported symptoms of depression (Reklaitiene et al., 2014). In a study in four European cities, van den Berg et al. (2016) demonstrated that more time spent in green space is associated with improved mental health and vitality independent of cultural and climatic contexts. General therapeutic benefits of nature engagement among people with autism have also been demonstrated (Faber Taylor & Kuo, 2006).

There is accumulating evidence for the beneficial effects of green space on mental health and cognitive development in children, although some studies produced inconsistent results. In a Lithuanian study, Balseviciene et al. (2014) found that living closer to city parks was associated with improved mental health in children whose mothers had a lower education level; however, more residential greenness was associated with worse mental health in children whose mothers had a higher education level.

Greater usage of green and blue spaces, and greater residential surrounding greenness, have been linked with improved behavioural development (reduced difficulties, emotional symptoms and peer relationship problems) and reduced rate of Attention Deficit Hyperactivity Disorder (ADHD) in children (Amoly et al., 2014). Annual time spent at the beach was negatively associated with behavioural difficulties, in particular peer relationship problems, but positively associated with strength in prosocial behaviour. Dadvand et al. (2015) demonstrated that greater surrounding greenness at home and school was associated with improved cognitive development (better progress in working memory and reduced inattentiveness) in schoolchildren. The association was partly mediated by reduced exposure to air pollution. A number of other studies have demonstrated the positive impact of green space exposure on ADHD and related symptoms (Faber Taylor & Kuo, 2011; van den Berg and van den Berg, 2011; Markevych et al., 2014).

2.3.2 Reduced cardiovascular morbidity

A study in the United Kingdom (Mitchell and Popham, 2008) found an association between low quantities of neighbourhood green space and elevated risk of circulatory disease. A study in Lithuania found that distance to green spaces has little or no influence on levels of known cardiovascular risk factors or the prevalence of coronary heart disease and stroke. However, there were significant associations between a more intense use of green space and reduced risk of cardiovascular disease (Tamosiunas et al., 2014). In a Lithuanian intervention study, Grazuleviciene et al. (2015b) found that walking in the park had a greater effect on reducing heart rate and diastolic blood pressure than walking in a busy urban street. They suggest that walking in a green space (such as a park) could be encouraged as rehabilitation from coronary artery disease.

Pereira et al. (2012) also found an inverse association between the levels and variability of neighbourhood greenness, which was assessed using NDVI data, and coronary heart disease or stroke in Australia. The odds of hospitalization and self–reported heart disease were lower for those living in neighbourhoods with highly variable greenness, compared to those with low variability in greenness. This effect was independent of the absolute levels of neighbourhood greenness. There was weaker evidence for associations with the mean level of neighbourhood greenness. The authors hypothesized that greater variability in neighbourhood greenness reflects two potential promoters of physical activity – an aesthetically pleasing natural environment and access to urban destinations.

2.3.3 Reduced prevalence of type 2 diabetes

It is well-known that type 2 diabetes mellitus can be prevented by life-style interventions that improve physical activity and reduce obesity. Therefore, it is plausible that access to green spaces can prevent diabetes by promoting more active lifestyles. Cross-sectional observational studies in The Netherlands, Australia and the United Kingdom demonstrated significant associations between neighbourhood greenness and reduced odds of having type 2 diabetes mellitus (Astell-Burt et al., 2014a; Maas et al., 2009b; Bodicoat et al., 2014). A study in Germany demonstrated an inverse association between neighbourhood greenness (measured by NDVI) and insulin resistance in adolescents (Thiering et al., 2016). The authors concluded that this apparent protective effect was due to vegetation reducing exposure to traffic-related air pollutants.

2.3.4 Improved pregnancy outcomes

A systematic review and meta-analysis (Dzhambov et al., 2014) showed that access to green space in close proximity to the homes of pregnant women was positively associated with birth weight. Birth weight is a useful indicator of health in early life: low birth weight is one of the major predictors of neonatal and infant mortality, as well as long-term adverse effects in childhood and beyond. Recent studies in Israel, Germany and England (Agay-Shay et al., 2014; Markevych et al., 2014; Dadvand et al., 2014b) also found a positive association between residential greenness measured by NDVI and birth weight. A study in Lithuania demonstrated that a larger distance to a city park from the homes of pregnant women was associated with increased risk of preterm birth and reduced gestational age at birth (Grazuleviciene et al., 2015a). However, a study in southern California in the United States showed only a weak relationship between green space and preterm births (Laurent et al., 2013). No association was found between greenness and preeclampsia (Agay-Shay et al., 2014; Laurent et al., 2013).

2.3.5 Reduced mortality

Evidence that exposure to urban green space is linked to reduced mortality rates is accumulating (reviewed by Gascon et al., 2016). Studies in Japan have shown that the five-year survival rate in individuals aged over 70 was positively associated with having access to more space for walking and with parks and tree-lined streets near the residence (Takano et al., 2002). Another study of pre-retirement age population in England showed evidence of the influence of the amount of green space in the neighbourhood on all-cause mortality (Mitchell and Popham, 2008). The study reinforced earlier findings based on the 2001 census population of England, which found that a higher proportion of green space in an area was associated with better self-reported health (Mitchell & Popham, 2007).

A recent longitudinal study of approximately 575,000 adults in Canada found that increased residential green space was associated with a reduction in mortality (Villeneuve et al., 2012); the strongest effect was on mortality from respiratory diseases. It should be noted that such findings may also reflect the type of urban development and availability of public transport or walkable streets. In Spain, Xu et al. (2013) showed that *perceived greenness* of neighbourhoods was associated with lower mortality risk during heat waves.

A recent systematic review demonstrated that the majority of previously conducted studies showed a reduction of the risk of cardiovascular disease (CVD) mortality in areas with higher residential greenness; results of meta-analysis supported the hypothesis that living in areas with higher amounts of green space reduces CVD mortality, while evidence of a reduction of all-cause mortality is more limited (Gascon et al., 2016). In the United States, residential proximity to green space has been associated with a reduced risk of stroke mortality (Hu et al., 2008) and with higher survival rates after ischemic stroke (Wilker et al., 2014). In contrast to the above findings, Richardson et al. (2012) did not find an association between availability of green spaces and overall mortality in the 49 largest US

cities. The authors suggested this might be due to the sprawling nature of US cities and higher levels of car dependency than in most European cities.

2.4 Mechanisms of potential pathogenic effects of green spaces

The evidence on adverse effects of urban green space or neighbourhood greenery on health is scarcer in comparison to the evidence of beneficial effects. An overview of some of these detrimental effects and their mechanisms is provided below (Lõhmus & Balbus, 2015).

2.4.1 Increased exposure to air pollutants

The interaction between trees, airflow and pollution is complex. While trees and vegetation may be effective in buffering airborne pollutants, in some cases, trees may trap and contain air pollution near busy roads when a closed canopy impedes the localized dispersion of vehicular emissions (Jin et al., 2014). However, it is possible to optimise urban greenery in order to avoid air pollution trapping by urban street trees (Jin et al., 2014).

Attractive nearby parks and open spaces may be associated with increased levels of physical exercise such as walking, as studies in England (Foster et al., 2004) and Australia (Giles-Corti & Donovan, 2003) have shown. However, where green space is adjacent to sources of pollution such as heavily trafficked roads, physical activity can be associated with elevated exposure to particulate matter, ozone, nitrogen dioxide, sulphur dioxide and other pollutants, especially under certain weather conditions (Carlisle & Sharp, 2001). Nonetheless, depending on urban air pollution levels, the benefits of physical exercise may still outweigh detrimental effects of exposure to pollutants. A study in more than 50,000 people aged 50-65 years, living in Denmark, showed that exposure to high levels of traffic-related air pollution did not modify associations between activity levels and mortality, demonstrating beneficial effects of physical activity on mortality even in the presence of air pollution (Andersen et al., 2015).

2.4.2 Risk of allergies and asthma

Evidence of associations between urban greenery, allergies and asthma is rather inconclusive. Lovasi et al. (2008) found that children living in areas with more street trees in New York City had lower asthma prevalence. A later cohort study involving minority children in New York City failed to show a hypothesized protective effect and, in fact, demonstrated a positive association between tree cover and allergic sensitization to tree pollen and asthma in children (Lovasi et al., 2013). Another study conducted in the United States reported that pollen associated with urban parks and trees was listed among the self-reported triggers of asthma in Philadelphia (Keddem et al., 2015). A study in Sabadell, Spain has not found an association between residential greenness and asthma; however, the same study showed that closer proximity to parks was linked with elevated prevalence of asthma (Dadvand et al., 2014a). Fuertes et al. (2014) used two birth cohorts (followed from birth to 10 years) in northern and southern Germany, and found that the relationship between greenness and allergies differed across their two study areas. In the urban south area, greenness was positively associated with allergic rhinitis and eyes and nose symptoms while in the rural north area, greenness appeared to have a protective effect.

2.4.3 Exposure to pesticides and herbicides

Living close to green spaces may be associated with elevated exposure to pesticides and herbicides especially if they are used in inappropriate ways and at excessive levels. The insecticides malathion and diazinon and the herbicide glyphosate, which is used to control weeds in urban parks, may be carcinogenic in humans (Guyton et al., 2015). The International Agency for Research on Cancer classified these compounds as *probably carcinogenic to humans* (IARC, 2015).

2.4.4 Exposure to disease vectors and zoonotic infections

Health risks from green space include vector-borne diseases, which are transmitted by arthropods, such as ticks (e.g. tick-borne encephalitis, Lyme disease), mosquitoes (e.g. Chikungunya fever, Dengue fever), or sandflies (e.g. visceral leishmaniasis). Lyme disease in particular has increased in Europe in the 21st century, and this has been associated with urban green space and increased animal hosts populations, such as deer, as well as with climate change and milder winters in northern Europe (Medlock and Leach, 2015).

Another health concern that often gains public attention is the contamination of urban green space with dog or cat faeces. Ingestion of dog faeces by young children can lead to toxocariasis (infections with *Toxocara canis*), with serious illness and blindness possible in rare circumstances. While well-managed parks and green space encourage dog walkers to remove dog faeces, limiting dog access to children's play areas is also important in order to control this disease (Despommier, 2003). Users of poorly maintained green spaces and playgrounds may also be exposed to *Toxoplasma gondii* in soil contaminated with cat faeces (Du et al., 2012; Afonso et al., 2008). This protozoan parasite of felines can also infect humans (as dead-end intermediate hosts) and cause severe neurological damage in children born to mothers who were infected for the first time during pregnancy.

2.4.5 Accidental injuries

Although physical activity in green spaces can have many positive benefits, as have been described earlier, it can also be associated with an increased risk of accidents and injuries, such as falls and drowning (Laosee et al., 2012). A study in the United Kingdom (Kendrick et al., 2005) showed that Accident and Emergency hospital admission rates were higher in wards with a greater number of parks and play areas per child under five years of age. Ball (2004) conducted a retrospective analysis of injury and fatality statistics associated with playgrounds in the United Kingdom. Most playground equipment related injuries occur in public urban green space, but the risk of serious injury in United Kingdom playgrounds is small, perhaps helped by the introduction of artificial, impact-absorbing surfaces.

2.4.6 Excessive exposure to UV radiation

While optimal levels of exposure to sun light are linked to health benefits (see section 2.2.10), greater time spent outdoors in green and open spaces may result in excessive exposure to sunlight and elevated risk of skin cancer. Astell-Burt et al. (2014b) showed that, in Australia, the odds of having skin cancer were higher for those living in a greener environment. The balance of risks or benefits for different levels of sunlight exposure is difficult to assess for various subpopulations. It should be noted that optimally designed green spaces and tree canopies can also provide protection against excessive exposure to UV radiation (Boldemann et al., 2006; Boldemann et al., 2011). In addition, the negative effects can largely be avoided or mitigated by simple means such as appropriate clothing, hats and sun block creams.

2.4.7 Vulnerability to crime

Crime against the person and anti-social behaviour are perceived risks from green spaces, as reported in some studies. However, this does not necessarily reflect recorded crime incidence (Bogar & Beyer, 2015). In a systematic review of fear of crime in urban green spaces, Sreetheran and van den Bosch (2014) found that the majority of the studies highlighted individual factors (such as gender and past experience) as more influential than social and physical factors in evoking fear of crime. They state that certain groups of people, particularly older people, women and ethnic minorities, tend to be more fearful because of their vulnerability or past experiences of crime.

There are varying relationships between green space and recorded crime found in reports from the United States. Groff and McCord's (2012) study in Philadelphia showed that neighbourhood parks were associated with increased levels of crime. However, certain characteristics of parks (such as the

presence of playing fields and courts) were associated with lower crime levels. In contrast, Troy et al. (2012), in a study of Baltimore, found a strong inverse relationship between urban tree canopy and violent crime.

2.5 Characteristics of urban green space associated with specific health benefits or hazards

Despite the growing research in this area, there is comparatively little evidence demonstrating differential health benefits associated with specific characteristics of green space. Varying configurations of green space, built environment and topographical features near a person's residence may offer different opportunities for physical activities and mental restoration, depending on the person's age, gender and individual preferences. An urban green space may have varying qualities that offer different opportunities for quiet relaxation, engagement with the natural environment, children's play, physical exercise and athletic activities or getting away from unpleasant aspects of the urban environment, such as noise or heat. More research is needed to identify attributes of green space that are associated with specific health benefits (Wheeler et al., 2015).

2.5.1 Perceptions of green space accessibility and quality

Research on the quality of green space associated with health benefits has often focussed on the physical activity mechanism (Giles-Corti et al., 2005; Hillsdon et al., 2006). A qualitative analysis (McCormack et al., 2010) revealed that attributes of green spaces, such as safety, aesthetics, amenities, maintenance and proximity to home, are important for supporting physical activity outdoors. Aspects such as concerns over safety, violence, graffiti, vandalism, litter, noise, pollution, and dog fouling had negative associations with park use and physical activity.

An Australian study suggested that higher levels of walking were associated with access to attractive, large public open spaces (Giles-Corti et al., 2005). A Dutch study (Van Dillen et al., 2012) assessed the quantity and quality of green space and their links to self-rated health. The quality, measured using characteristics such as accessibility, maintenance, absence of litter and safety, was positively associated with general health. The authors suggested that the quality of green space predicted health outcomes independently of the quantity of the greenspace. Sugiyama et al. (2013), in an Australian study, found no associations between initiation of walking and green space quality (defined as "pleasant natural features") and proximity. However, proximity of green spaces, and access to a comparatively large sized green space within 1.6 km of a person's home, were associated with maintenance of walking. The attractiveness of green space has also been associated with increased recreational walking (Sugiyama et al., 2010).

Also working in Australia, Wang et al. (2015) found that positive attitudes to the experience of visiting green space and perceptions of its accessibility appear to matter more than independently measured geographic attributes in predicting green space use.

In Sabadell, Spain, Dadvand et al. (2014a) found greener residential areas, as measured by NDVI, and proximity to forests were associated with lower prevalence of being overweight or obese in children. As noted in section 2.3.2, Pereira et al. (2012), working in Australia, found that a greater variability in greenness has a protective effect on coronary heart disease or stroke in adults. People living in neighbourhoods with greater variability in greenness are likely to have access to aesthetically pleasing natural environment and also to urban destinations – both factors stimulating walking.

The qualities of green space in terms of allowing *relaxation* and *recreation* have been described as important factors in improving mental well-being (Pope et al., 2015). It was shown that the quality of public open spaces (including parks and gardens) in the neighbourhood is more relevant to mental health, than their quantity (Francis et al., 2012). Grahn & Stigsdotter (2010) identified eight perceived sensory dimensions of urban parks or urban open spaces: *Serene*, *Space, Nature, Rich in Species, Refuge, Culture, Prospect* and *Social.* Among these, the dimensions *Refuge* and *Nature* were

strongly negatively correlated with stress. *Refuge* was defined as a place surrounded by bushes and higher vegetation where people feel safe, play and can observe other people being active; *Nature* was defined by the feeling of "being in nature". Two longitudinal studies (Annerstedt et al., 2012; Van den Bosch et al., 2015) have shown that access to the *Serene* dimension was associated with a significantly decreased risk of mental illness in women. *Serene* has been previously defined by Grahn & Stigsdotter (2010) as "a holy and safe place, which is a calm environment, undisturbed and silent" (p. 271).

2.5.2 Size of green space

The size of green space is likely to influence the levels and types of activity people undertake within it. Sugiyama et al. (2010) suggested that the attractiveness of a space and the options for activity that the space provides may be more relevant for physical activity than the number of open spaces available. This Australian study considered parks with a size range of approximately 1-10 ha. The authors proposed that, when planning and designing green space to encourage physical activity, it might be better to consider provision of one large park in the neighbourhood rather than many smaller parks. A study of young people in the United States (Epstein et al., 2006) supported this view and showed substantial increases in estimated time in moderate to vigorous physical activity for youth who lived near large parks.

There is a need for more evidence on the effects of configuration and connectivity of green space on health outcomes. What green space offers in terms of facilities, programmes of events, formal game pitches, health trails, cycling, walking and jogging routes, opportunities to be used en route to daily destinations such as school, work or shops, etc. will be affected not only by design and management of green space but also by its size, shape, topography and/or configuration in relation to broader infrastructure and the distribution of different land uses in the urban area (Robertson et al., 2012).

2.5.3 Presence of specific facilities for certain activities

What the environment offers can enable or deter outdoor activities. A study in Ontario, Canada, (Kaczynski et al., 2008) found that park facilities such as a paved trail, water area, and playground were more important for physical activity than park amenities such as a drinking fountain, picnic area, and restroom; paved trails in particular were strongly associated with physical activity.

Schipperijn et al. (2013) reported that levels of physical activity in the nearest urban green space were positively related to features such as walking/cycling routes, wooded areas, water features, lights, pleasant views, a bike rack, and a parking lot. A study in the US (Oreskovic et al., 2015) demonstrated that playground use was associated with higher levels of physical activity among adolescents aged 11-14 years.

In a study involving older women, Chastin et al. (2014) found that the lack of resting places outside the home strongly limited participants' motivation or confidence to be active. Most said they would walk more if they could find resting places at staggered intervals in public spaces, enabling them to rest when needed and giving them increased confidence to venture further outside. This confirms other research that has identified the value of trees and greenery as attractors for older people to use the outdoor environment, but also the importance of seating and facilities such as toilets to enable older people's access to and enjoyment of public green space (Aspinall et al., 2010).

2.5.4 Tree cover and canopy density

It has been claimed that urban greenery can contribute to a substantial reduction in the urban heat island effect (Tan et al., 2015). However, in a study of all-cause mortality during heat waves in Barcelona, Spain, greater percentage of tree cover was *not* associated with reduced mortality risk (Xu et al., 2013), although residents' perception of little surrounding greenness *was* significantly associated with mortality.

In a laboratory environment in the United States, Jiang et al. (2014b) assessed the role of tree canopy density in self-reported stress recovery by showing study participants 3-D videos containing different levels of tree canopy in an urban environment. The authors found a positive linear association, indicating that higher levels of tree density were associated with greater self-reported stress reduction. By measuring the participants' physiological stress reaction by salivary cortisol and skin conductance, Jiang et al. (2014a) found that men had a greater stress reduction from moderate tree density cover, rather than high or low levels; the same was not found for women.

The presence of nearby trees and grass visible from apartment buildings has been shown to lower levels of aggression and mental fatigue in residents, in comparison to those living in buildings overlooking barren vistas (Kuo and Sullivan, 2001). Also, the absence of green elements near housing has been shown to impact negatively on the management of major life issues (Kuo, 2001). However, some qualities of green spaces associated with tree cover, especially when overgrown or unmanaged, may increase levels of anxiety due to fear of crime, resulting in a negative impact on people's well-being (Kuo et al., 1998). In Baltimore, tree canopy has also been identified as having a potential beneficial effect towards increased social capital (Holtan et al., 2015).

2.6 Differential health benefits of green spaces in specific population groups

While the studies described above have shown that urban green spaces provide health benefits for a variety of populations, many studies also showed differing health outcomes dependent on demographic factors, including gender, age, ethnicity and socioeconomic status (Charreire et al., 2012; Dadvand et al., 2012b; Lachowycz and Jones, 2011; Lachowycz and Jones, 2014; Maas et al., 2009b; Xu et al., 2013). The section below focuses on studies where particular subgroups have been shown to experience differential health benefits from green space.

2.6.1 Women

As indicated in earlier sections, there is evidence that women and men experience and respond to urban green space in different ways. A systematic review (Sreetheran & van den Bosch, 2014) summarizing findings from many studies demonstrated that women, through perceiving themselves to be more vulnerable, were more fearful in urban green spaces than men. Conversely, Krenichyn's (2006) study of women's use of a large, green park in New York City found that they enjoyed exercise in the park compared to exercising in the street because of the beautiful scenery and its therapeutic or spiritual qualities. By contrast with the harassment (catcalls and male comments) experienced when exercising in the street, the park afforded a traffic-free environment where women felt freer to dress comfortably and less susceptible to unwelcome remarks. Thus, appropriately managed green space may offer women opportunities to be more physically active than in other urban contexts.

Positive associations between green space and mental health have also been found for women differentially from men. For example, van den Bosch et al. (2015) found a significant relationship between access to 'serene' green space and improved mental health in women but not men. Using measures of diurnal salivary cortisol secretion as a biomarker of stress, Roe et al. (2013) found that effects of green space exposure on patterns and levels of cortisol were different in men and women. More green space in the residential area was associated with a steeper decline in salivary cortisol from three to nine hours post-awakening (healthier diurnal cortisol pattern) in both genders. However, women with lower exposure to green space were found to have a higher rate of hypocortisolemia (low cortisol level at three hours post-awakening), indicating long-term dysregulation of the psychoneuroendochrine system. In men, post-awakening cortisol levels were not associated with green space; instead, men living is less green areas had a shallower decline in cortisol level through the day, resulting in elevated cortisol levels at six and nine hours post-awakening, also indicating psychoneuroendocrine dysregulation.

There is considerable evidence of beneficial effects of access to green space for the health of pregnant women. Specifically, studies in Europe showed positive associations between access to

nearby green space and both reduced blood pressure and reduced depression in pregnant women, with a stronger effect for reduced depression in disadvantaged groups (McEachan et al., 2016; Grazuleviciene et al., 2014).

Such findings suggest it is important to take gender into account when considering any associations between urban green space and health, since both physiological and psychological responses to green space may differ.

2.6.2 Children and adolescents

It has been shown that exposure to green spaces during pregnancy has beneficial effects on *in-utero* development. Studies in Israel, Germany and England (Agay-Shay et al., 2014; Markevych et al., 2014; Dadvand et al., 2014b) and a systematic review and meta-analysis (Dzhambov et al., 2014) demonstrated links between better access to green space during pregnancy and increased birth weight.

Adequate exposure to green space in children may not only facilitate healthy development in childhood but also provide long-term health benefits through adulthood. It has been shown that socio-environmental risk factors in prenatal life, infancy and childhood also have an effect over the entire life-course (Gluckman and Pinal, 2001; Gluckman, 2012; Gluckman et al., 2007). In general terms, if access to green space can stimulate the development of gross and fine motor skills as well as cognitive, emotional, social and physical development in children (Strife & Downey, 2009), then these may lead to better health and better ability to maintain healthy lifestyles in adulthood.

There is some evidence that exposure to green space can influence cognitive development in children. Dadvand et al. (2015) showed a beneficial association between exposure to green space (surrounding greenness at home and school and during commuting) and measures of cognitive development in primary schoolchildren. This association was partly mediated by reduction in exposure to air pollution. Other studies have also demonstrated that green spaces are linked to improved development, reduced problematic behaviour and reduced risk of ADHD (Amoly et al., 2014; Faber Taylor & Kuo, 2011; van den Berg & van den Berg, 2011; Markevych et al., 2014).

According to research in Switzerland, public urban green spaces play an important role in children's and young people's social networks, including friendships across cultures, promoting social inclusion (Seeland et al., 2009).

More generally, understanding links between green space and children's health includes consideration of risks and the importance of learning to manage risk as children develop into adults. Research in the United Kingdom has shown that there is a great attraction in risky and adventurous activity, especially for adolescent boys. Wild or natural environments that offer challenge within an accessible context can help satisfy this need for risky and adventurous behaviour among adolescents (Natural England, 2010b). Opportunities to develop skills in risk management and coping with uncertainty, important attributes for adulthood, are often unavailable to teenagers and young people unless they are introduced to wilder areas and risky situations (Natural England, 2010b). Green space of certain types can offer this even in an urban environment and may be the only accessible option for many.

2.6.3 Older adults

A positive relationship between the amount of green space and self-reported health in senior adults was demonstrated in the Netherlands (de Vries et al., 2003). The beneficial effect of green space was stronger in senior citizens and in housewives than in the general population, perhaps due to these groups' greater dependence on the local living environment.

Toussaint et al. (2015) explored the role of green spaces in sleep deficiency and found a stronger protective effect for people aged 65 and older, compared to younger adults.

Sedentary behaviour is an important health hazard in older adults, who are often the most sedentary segment of society. A recent systematic review found that, when measured objectively, 67% of adults aged 60 years and over spent more than 8.5 hours of their waking day sedentary (Harvey et al., 2013). Evidence of beneficial effects of green spaces on physical activity in individuals aged 60 years or older is summarized by Broekhuizen et al. (2013).

Older adults living in inner-city neighbourhoods also benefit from the presence and use of green spaces, which appears to promote social ties and a sense of community (Kweon et al., 1998). Social contact is known to be important for health and well-being, especially for older people, where social isolation has been significantly associated with increased mortality (Steptoe et al., 2013).

2.6.4 Deprived subpopulations and minority groups

There is accumulating evidence showing that urban green space may be 'equigenic' (Mitchell et al., 2015), i.e. that the health benefits linked with access to green space may be strongest among the lowest socioeconomic groups, including minority ethnic groups.

Mitchell & Popham's (2008) study of the association between green space and mortality rates in England found that populations exposed to the greenest environments had the lowest level of health inequality related to income deprivation.

Lachowycz & Jones's (2014) study in the United Kingdom confirmed an association between green space access and reduced cardiovascular mortality found previously (Mitchell and Popham, 2008; Villeneuve et al., 2012) but only amongst the most socioeconomically deprived groups. Pope et al. (2015) identified significant associations between reported access to, and better quality of, green space and reduced psychological distress in a deprived urban population in the US. In a large European epidemiological study, Mitchell et al. (2015) found that socioeconomic inequality in mental well-being was 40% narrower among respondents reporting good access to green space, compared with those with poorer access.

One way in which good access to green space may contribute to reduced health inequalities in income-deprived communities is through frequency of and/or time spent in outdoor activities. As stated earlier, evidence suggests that activities in green space may offer psychological, physical and social health benefits. Improvements in access to woodland green space near deprived urban communities in Scotland, United Kingdom, positively impacted on green space use and may have contributed to improvements in activity levels and perceived quality of life (Ward Thompson et al., 2013).

There is a common tendency for the most deprived urban communities to experience the poorest air quality, as has been shown for the United Kingdom (Grant et al., 2012) and Norway (Naess et al., 2007). This can contribute to excess mortality in deprived neighbourhoods. Thus, urban green space in deprived areas may reduce health disparities by mitigating air pollution.

In the United States, Harlan et al. (2006) showed that individuals of lower socioeconomic status and minority groups in Phoenix, Arizona, were more likely to live in neighbourhoods with greater exposure to heat stress. Jenerette et al. (2011) suggest that such lower income populations have less means to cope with extreme temperatures. While wealthier people may have access to cooling systems, the low income population relies more on what is publicly available. Therefore, the role of vegetation in cooling urban areas may be especially important for the urban poor.

Sreetheran and van den Bosch (2014), in a systematic review of English language literature, found that being an ethnic minority and living in low income neighbourhoods affects feelings of security in urban green spaces. It seems that those minority respondents who feared visiting parks or playgrounds had experienced previous direct or indirect victimization in their local urban green spaces. Dadvand et al. (2014b) found a positive association between levels of surrounding greenness during pregnancy and babies' birth weight in a white British population but not for those of Pakistani

origin, suggesting a difference between ethnic groups that may reflect wider perceptions and use of green space.

Many minority ethnic groups living in European cities suffer socioeconomic deprivation and comparatively poor health. One study on black and minority ethnic (BME) groups in England (CABE 2010a) showed that many BME people live in the most deprived census wards in the United Kingdom and that such wards had, on average, only a fifth of the area of green space that is available to the most affluent wards. The study also showed that in areas most densely populated by BME groups (i.e. comprising 40% plus of population), the available green space is of poorer quality. A second study (CABE 2010b) found that the quality of, access to, and use of urban green space was a significant predictor of general health for African Caribbean, Bangladeshi, Pakistani and other BME groups, who were also those with the poorest health (Roe et al., 2016). Thus, provision and maintenance of appropriate green space in urban areas may make an important contribution to reducing health inequalities.

2.6.5 Populations of various countries and geographic regions

Some findings, such as the stress reduction opportunities that urban green space affords, have been replicated in multiple studies conducted in different countries. However, most of the epidemiological studies cited above have been conducted in high income countries (mainly in western and northern Europe, as well as in North America, Australia and Japan). There is a need for more research on urban green space and health in the eastern parts of the WHO European Region. Such research is essential for assessing health benefits of urban green spaces in middle and low income countries and in cities with different urban design characteristics.

2.7 Co-benefits of urban green spaces unrelated to health effects

There are many co-benefits that may arise from good planning, design and management of urban green spaces in addition to improved public health. While this review focuses on health benefits of urban green spaces, potential additional benefits are briefly summarized below.

The European Commission (European Union, 2015) calls for attention to ensuring sustainable urbanization through promoting nature-based solutions including provision of accessible green spaces. The economic importance of, and return on, investment in urban green space is a budgetary issue for urban planners, social services, and other professionals. Co-benefits of investment in green space may include enhanced economic competitiveness of cities, where quality of life is important for attracting and retaining a skilled workforce (KPMG, 2012a). An attractive and usable green environment near residential areas is likely to increase property values (Wachter & Bucchianeri, 2008) and create ‘liveable’ urban areas that attract new residents and investment, and facilitate economic sustainability (KPMG, 2012b). Equally urban green space has been shown to benefit economically deprived urban communities more than others, creating more equal socioeconomic conditions (CABE, 2004). A recent study concluded that investing in green infrastructure in cities, might not only be ecologically and socially desirable, but also quite often, economically advantageous (Elmqvist et al., 2015).

A green urban environment that supports health in general may also produce healthier workforces, enhancing people’s quality of life as well as their productivity and earning potential. Losses of productivity due to obesity and depression are major cost factors affecting businesses. Thus, improving access to green space can improve mental and physical health and produce major economic benefits through reduced absenteeism and improved productivity. Also, investment in green space may also create green jobs and offer the potential to enhance tourism (Cianga & Popescu, 2013).

A recent review showed that urban parks function as biodiversity hotspots (Busse-Nielsen, 2013). Well-designed urban green space can also benefit hydrological systems and enhance sustainable

urban drainage, help prevent and mitigate flooding and create and extend new habitats for plant and animal species (Gill et al., 2007). Green space may also offer opportunities for environmental education and engagement with nature at every age category, from young children to senior adults (Dadvand et al., 2015; Natural England, 2010b; Sugiyama et al., 2009).

Green spaces can also improve urban ecosystem health by reducing the effects of weather extremes and air pollution (LRTAP Working Group on Effects, 2013). Similarly, noise reduction by green space may benefit species other than human (Francis et al., 2009).

The use of urban green space for low-carbon commuting, e.g. by walking or cycling to school or to work, can reduce greenhouse gas emissions and contribute to mitigating global climate change. Urban green space can make active travel attractive and thereby encourage and support new, environmentally friendly behaviours (Scottish Government, 2016).

In addition to general opportunities for social cohesion, urban green space may also offer the chance to develop individual and community capital. Public green places, for example, offer opportunities for bigger groups to gather than is possible in the home. Urban green spaces that can also be adapted for different temporary uses, such as festivals and cultural events. Finally, urban green space may play an important role in enhancing community resilience and helping communities cope with natural disasters and extreme weather events (Tidball & Krasny, 2014).