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Review

Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review

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Abstract

Europe is a highly urbanised continent. The consequent loss and degradation of urban and peri-urban green space could adversely affect ecosystems as well as human health and well-being. The aim of this paper is to formulate a conceptual framework of associations between urban green space, and ecosystem and human health. Through an interdisciplinary literature review the concepts of Green Infrastructure, ecosystem health, and human health and well-being are discussed. The possible contributions of urban and peri-urban green space systems, or Green Infrastructure, on both ecosystem and human health are critically reviewed. Finally, based on a synthesis of the literature a conceptual framework is presented. The proposed conceptual framework highlights many dynamic factors, and their complex interactions, affecting ecosystem health and human health in urban areas. This framework forms the context into which extant and new research can be placed. In this way it forms the basis for a new interdisciplinary research agenda.

Keywords: Public health; Human well-being; Green Infrastructure; Urban ecosystem; Ecosystem health

Contents

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1. Introduction

The United Nations (2001) estimated that the level of urbanisation in Europe will increase to almost 80% by 2015, compared to 75% in 2000. Urban growth, by altering cities and the surrounding countryside, presents numerous challenges for the maintenance of urban green space, and consequently also for human health and well-being.

The link between an individual's socio-economic position and their health is well-established (e.g. Bartley et al., 1997; Brunner, 1997; Davey-Smith et al., 1997, 1990). Furthermore, epidemiological studies have provided evidence of a positive relationship between longevity and access to green space (Takano et al., 2002; Tanaka et al., 1996), and between green space and self-reported health (de Vries et al., 2003).

The World Health Organization defines human health as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (WHO, 1948). This definition implies that to fully understand and describe the concept of health a wide array of related factors ought to be considered including, amongst others, biological, psychological and social.

Ecosystem health is generally defined as the occurrence of normal ecosystem processes and functions (Costanza, 1992). A healthy ecosystem is thought of as one that is free from distress and degradation, maintains its organisation and autonomy over time and is resilient to stress (Costanza, 1992; Mageau et al., 1995; Costanza et al., 1998; Rapport et al., 1998; Lu and Li, 2003). Some authors have pointed out that defining ecosystem health depends on human-social values and desires (Lackey, 1998; Brussard et al., 1998). Therefore, the concept of ecosystem health, like that of human health, integrates numerous ecological, social, economic and political factors. But, how is it possible to conceptualize the integration of socio-ecological systems in urban areas?

The importance of considering human-social systems when studying urban ecological systems has been emphasised (Groffman and Likens, 1994; Grimm et al., 2000; Zipperer et al., 2000; Kinzig and Grove, 2001; Yli-Pelkonen and Niemelä, 2005; Yli-Pelkonen and Kohl, 2005). To do this it is necessary to develop and use interdisciplinary approaches that integrate biological, social and other sciences to provide a better understanding of the challenges of land use planning and management (Massa, 1991; Berkes and Folke, 1998; Haeuber and Ringold, 1998; Collins et al., 2000; Devuyst et al., 2001; Kinzig and Grove, 2001; Ehrlich, 2002). The issues associated with integrating socio-ecological systems, i.e. different academic traditions and research methods, specialised language (Massa, 1991) and the lack of common theories (Moss, 2000), are complex and constitute a major obstacle to interdisciplinary studies. Nonetheless, such approaches are necessary if the challenges faced by those involved in land use planning and management are to be addressed fully.

2. Aim and objectives

The aim of the paper is to integrate literature on the concepts of Green Infrastructure and ecosystem health with that on human health, and to formulate a conceptual framework based on the resultant new understanding. This is achieved through addressing three objectives: (a) constructing a set of definitions; (b) undertaking a critical review of the literature on associations between Green Infrastructure components and ecological and human health; (c) constructing a conceptual framework of the interface between these disciplines. This conceptual framework will help organise existing and new insights, and help in formulating new research questions regarding ecosystem and human health. This review is an important step in stimulating debate on integrating urban Green Infrastructure components and planning in public health promotion.

3. Methods

Electronic journal databases (i.e. Web of Knowledge, Science @ Direct and Infotrac—Health & Wellness Resource Centre) were first searched by journal name to identify journals in urban nature conservation, ecosystem health, environmental psychology and public health. At this stage only peer reviewed publications were selected for the subsequent selection of articles. The journals included in the literature review were *Landscape and Urban Planning*, *The Journal of Environmental Psychology*, *Environment and Behaviour*, *Ecosystem Health*, *The British Medical Journal*, and *Preventative Medicine*. Using the keywords of Green Infrastructure, ecosystem health, human health, well-being and conceptual models, relevant articles from these journals were identified. Additionally, landmark book publications where included in the literature review.

The articles were critically evaluated by conducting a strengths and weaknesses analysis of the study design and interpretations. Since causal relationships between Green Infrastructure components and human health are difficult to establish and quantify this critical literature review covered studies that focussed on association rather than causation.

The literature reviewed revealed a number of themes and relationships that relate to Green Infrastructure, ecosystem health and human health. These themes and relationships were used to construct a conceptual framework. The themes were summarised and classified into seven thematic groups each one

comprising a number of elements. Then, the dynamic nature of relationships between Green Infrastructure, ecosystem health and human health were illustrated. This was achieved by organising the themes and relationships, in the conceptual framework, according to associations that have been empirically evaluated by published studies.

4. Definitions

The concept of Green Infrastructure has been introduced to upgrade urban green space systems as a coherent planning entity Sandström (2002). It can be considered to comprise of all natural, semi-natural and artificial networks of multifunctional ecological systems within, around and between urban areas, at all spatial scales. The concept of Green Infrastructure emphasises the quality as well as quantity of urban and peri-urban green spaces (Turner, 1996; Rudlin and Falk, 1999), their multifunctional role (Sandström, 2002), and the importance of interconnections between habitats (van der Ryn and Cowan, 1996). If a Green Infrastructure is proactively planned, developed, and maintained it has the potential to guide urban development by providing a framework for economic growth and nature conservation (Walmsley, 2006; Schrijnen, 2000; van der Ryn and Cowan, 1996). Such a planned approach would offer many opportunities for integration between urban development, nature conservation and public health promotion.

The WHO (1948) defines health as being a state of complete physical, mental and social well-being. A key concept within public health is that of well-being, which encompasses a wide array of biological, sociological, economical, environmental, cultural and political factors. The term well-being is used in the WHO (1948) definition of health. Within research well-being has been variously defined by socio-economic, psychological and psychosocial variables (Rioux, 2005), as well as by the feelings of connectedness to nature (Mayer and McPherson-Frantz, 2004). The Millennium Ecosystem Assessment adopted a broad definition of "well-being" that includes material security, personal freedoms, good social relations and physical health (Millennium Assessment, 2003).

Medical science and epidemiology have traditionally focused on biological and individual-level factors affecting health and well-being. Since the 1990s there has been an increase in multilevel studies exploring the role of socio-economic and environmental factors in public health (e.g. de Vries et al., 2003; Dunn and Hayes, 2000; Ross, 2000; Diez-Roux et al., 1999, 1997; Macintyre et al., 1993). Multilevel approaches (e.g. social epidemiology) are important in identifying a varied range of socio-economic and environmental factors affecting public health. However, multilevel studies have not been readily accepted within epidemiology (Zielhuis and Kiemeney, 2001). This has been attributed to the lack of theoretical foundations and unresolved methodological issues (O'Campo, 2003) as well as to the dominance of conceptual and political individualism in epidemiology (Macintyre et al., 2002). Nonetheless, social epidemiology can contribute to a better understanding of socio-economic and environmental determinants of health. Further work is needed in testing theoretical assumptions and developing rigorous methodological approaches in order to advance the field (O'Campo, 2003).

The concept of health in ecology generally refers to habitats, whether managed or pristine, that are characterised by system integrity and exhibit properties of a self-organising, complex systems (Rapport and Whitford, 1992). The concept of ecosystem health has been variously defined (Table 1) and the definitions have been closely allied with the concepts of stress ecology (Barrett and Rosenberg, 1981; Odum, 1985; Rapport, 1989). On this basis, an ecosystem can be considered as healthy when it is free from, or resilient to, stress and degradation, and maintains its organisation, productivity and autonomy over time (Costanza, 1992; Rapport et al., 1998; Brussard et al., 1998; Karr et al., 1986).

The concept of ecosystem health is not unanimously accepted (Calow, 1992; Suter, 1993; Wicklum and Davies, 1995). It has been criticised for creating a metaphor of "ecosystem as organism" (Rapport et al., 1998), for focusing on equilibrium theories (de Leo and Levin, 1997), and for not emphasising that ecological communities are open, loosely defined assemblages with only weak evolutionary relationships to one another (Levin, 1992). Nonetheless, Lu and Li (2003) see modelling of ecosystem health as an organising framework for protecting and sustaining environmental quality and human well-being. However, models of ecosystem health ought to be constructed under the new ecological paradigm (i.e. open systems with dynamic interrelationships).

5. Green Infrastructure and ecosystem health

The elements and components of a complete Green Infrastructure could contribute to ecosystem health in various ways. Urban and peri-urban habitats increase the overall vegetation cover (natural, semi-natural and artificial), thus contributing to conservation of biological diversity (Bratton, 1997; Flores

Table 1
Studies defining ecosystem health

Author	Type of study	Keywords
Lu and Li (2003)	Model of ecosystem health	Vigour index; resilience index; organization index
Brussard et al. (1998)	Discussion of ecosystem management	Ecosystem viability or health = current utility, future potential, containment, resilience
Lackey (1998)	Discussion of ecosystem management	Ecological health = ecological integrity; need to define the desired state to achieve desired social benefits
Costanza (1992)	Model of ecosystem health	Vigour, organization, resilience

et al., 1998). Furthermore, a Green Infrastructure maintains the integrity of habitat systems and may provide the physical basis for ecological networks. The development of ecological networks has been advocated as a means of alleviating the ecological impacts of habitat fragmentation. This makes biodiversity conservation an integral part of sustainable landscapes (Opdam et al., 2006).

Only a few empirical studies have shown the successful role of ecological corridors as conduits for wildlife (e.g. Haddad and Tewsbury, 2005). So, the functionality of corridors in ecological networks remains contested (Noss, 1993; Hobbs, 1992; Beier and Noss, 1998; Simberloff et al., 1995). However, in the absence of alternative strategies for addressing the ecological impact of fragmentation, ecological networks have become a popular element of urban planning (Jongman and Pungetti, 2004).

The elements of a Green Infrastructure can be seen as preserving and enhancing diversity within ecosystems in terms of habitats, species and genes. Diversity is one of the most important indicators of ecosystem health (Rapport, 1995). Species-rich heterogeneous habitats are considered to be more resilient than homogenous habitats (Bengtsson et al., 2002). Furthermore, it is commonly hypothesised that species-rich communities are more resistant to invasion than species-poor communities, because they use the available resources more efficiently (Loreau et al., 2002). Therefore, species-rich ecosystems are considered to maintain their organisation better than less diverse ones. Additionally, species-rich ecosystems have higher productivity, or vigour, than simpler ecosystems (Naeem et al., 1996; Tilman, 1997). Therefore, a Green Infrastructure could have an influence on urban and peri-urban ecosystem health by contributing to ecosystem resilience, organisation and vigour.

Rapport et al. (1998) saw that linking ecosystem health to the provision of ecosystem services, and determining how an ecosystems' health (or alternatively dysfunction) related to these services, presents major challenges at the interface of health, social and natural sciences. The term "ecosystem service" refers to the delivery, provision, protection or maintenance of goods and benefits that humans obtain from ecosystem functions (Millennium Assessment, 2003; de Groot et al., 2002; Bolund and Hunhammar, 1999). The link between ecosystem health and public health is the set of ecosystem services provided by the Green Infrastructure.

Ecosystem functions include biotic, bio-chemical and abiotic processes, within and between ecosystems (Turner et al., 2005; Brussard et al., 1998). From these fundamental ecosystem functions, numerous ecosystem services can be provided. de Groot et al. (2002), in a non-exhaustive list, identified no less than 32 ecosystem services including biological, physical, aesthetic, recreational and cultural. Cultural, psychological and other non-material benefits that humans obtain from contact with ecosystems contribute in particular to human health in urban settings (Butler and Oluoch-Kosura, 2006).

The benefits of biodiversity for human well-being are generally determined by the diversity of habitats and species in and around urban areas (Tilman, 1997). There is a close relationship between ecosystem health and ecosystem services: i.e. increasing ecological stress leading to a reduction in both the quality and quantity of ecological services (Cairns and Pratt, 1995). In contrast, healthy ecosystems have the capacity to provide a comprehensive range of ecosystem services (Costanza et al., 1998; Lu and Li, 2003). Therefore, ecological functions and ecosystem services derived from a Green Infrastructure contribute to ecosystem health and to public health, respectively.

6. Green Infrastructure and human health

6.1. Epidemiological studies

The links between socio-economic status and health are well-established (e.g. Dunn and Hayes, 2000; Ross, 2000; Diez-Roux et al., 1999, 1997; Macintyre et al., 1993; Bartley et al., 1997; Brunner, 1997; Davey-Smith et al., 1997, 1990). The EU Strategy on Environment and Health (EC, 2003) and the European Ministerial Conferences on the Environment and Health Process recognised that poverty and social factors are the main determinants of human health, but environmental threats are recognised too. An accumulating set of studies provide evidence, albeit still rather weak, on the positive relationship between well-being, health and green space (de Vries et al., 2003; Takano et al., 2002; Tanaka et al., 1996).

Epidemiological studies, controlled for age, sex, marital and socio-economic status, have provided evidence of a positive relationship between senior citizens' longevity and green space (Takano et al., 2002; Tanaka et al., 1996). Also, when controlled for socio-economic and demographic characteristics and for level of urbanity, positive relationships have been revealed between green space and self-reported health (de Vries et al., 2003). The possibility of selection bias remains with the de Vries et al. (2003) study as the sample, although large ($N = 10197$), was drawn from people visiting primary care facilities. Payne et al. (1998) found that park users reported better general perceived health, higher levels of activity and the ability to relax faster. Even though these studies were controlled for socio-economic factors, the possibility of confounding factors is impossible to exclude; especially in relation to lifestyle that may be prevalent in communities near parks.

A possible mechanism explaining the relationship between the amount of green space, well-being and health has been hypothesized (cf. de Vries et al., 2003; Takano et al., 2002). Green areas in one's living environment may ameliorate air pollution, and the urban heat island effect (Whitford et al., 2001), and may also lead to people spending a greater amount of time outdoors and being more physically active. Indeed, there is a rapidly accumulating body of theoretical (Humpel et al., 2002) and empirical evidence of the importance of physical environmental influences on neighbourhood walking and physical activity. Evidence of the association between levels of physical activity and proximity of green areas in the neighbourhood have been provided in studies which have controlled for age, sex and education level (Booth et al., 2000; Humpel et al., 2004; Pikora et al., 2003).

Regarding social outcomes of green space Kim and Kaplan (2004) suggested that natural features and open spaces in a

residential area play an important role in residents' feelings of attachment towards the community, and their interactions with other residents. On the other hand, green spaces that are perceived to be overgrown or unmanaged may have a negative effect on peoples' well-being by increasing anxiety caused by fear of crime (Kuo et al., 1998; Bixler and Floyd, 1997). Additionally, urban and peri-urban ecological changes can affect the geographical range of diseases such as Lyme disease (Patz and Norris, 2004) and West Nile Virus (Zielinski-Gutierrez and Hayden, 2006). Hence, the positive benefits of green space cannot be generalised. Future research will show whether it is possible to quantify environmental influences and subsequent positive or negative health outcomes from different types and configurations of urban Green Infrastructure. Further research is also required to establish different possible health responses to natural, semi-natural or artificial habitats.

6.2. Experimental studies

A second mechanism explaining the relationship between the amount of green space, well-being and health can be hypothesized. Even passive viewing of natural environments after negative antecedent conditions, such as attention fatigue (Kaplan and Kaplan, 1989) or psycho-physiological stress (Ulrich, 1984), produces stress-ameliorating effects which may ultimately confer health benefits (Ulrich, 1984). For example, a 10 min video exposure to an everyday nature view (dominated by trees, vegetation or water) after exposure to a stressor video, produced significant recovery from stress within 4–7 min. This was indicated by lowered blood pressure, muscle tension and skin conductance in a study where subjects were randomly assigned to urban or natural video conditions (Ulrich et al., 1991). Evidence of improved attention functioning, and emotional gains (Hartig et al., 1991) as well as lowered blood pressure (Hartig et al., 2003) in natural settings, has also been found in controlled field experiments where subjects were randomly assigned to a slow walk in either urban or natural environments.

Experimental research has also begun to investigate the effect of natural versus urban environments on restoration gained through running (Bodin and Hartig, 2003). Nearby trees and grass visible from apartment buildings have been shown to enhance residents' effectiveness in facing their major life issues and to lessen intra-family aggression by reducing mental fatigue (Kuo, 2001; Kuo and Sullivan, 2001). These studies used statistical mediator variable analysis to demonstrate the relationship between green elements and psychological variables. Moreover, Faber-Taylor et al. (2001) found that, according to parents' assessments, 7–12-year-old children with attention deficit disorder functioned better than usual following participating in activities in green settings. Also, it is reported that the greener a child's play area was, the less severe his or her attention deficit symptoms were (Faber-Taylor et al., 2001). Similarly, Wells (2000) studied American 7–12-year-old, low-income, urban children before and after relocation. He found that whilst the change in the overall housing quality was not a significant predictor of ability to focus attention, children whose homes improved the most in terms of natural views tended to have the highest levels of attention capacity.

A mechanism to explain human affiliation or aversion towards biodiversity has been expressed in the biophilia and biophobia hypotheses. The biophilia hypothesis suggests a biologically based, inherent human need to affiliate with life and lifelike processes (Kellert and Wilson, 1993). It is stipulated in this hypothesis that contact with nature is fundamental to psychological well-being and personal fulfilment (Kellert and Wilson, 1993). On the other hand, the biophobia hypothesis, based on psycho-evolutionary reasoning, suggests that certain aspects of biodiversity elicit fear and avoidance, due to association with danger (Ulrich, 1993). Although there is no direct empirical evidence for either hypothesis, there is compelling logical reasoning for them (Pretty et al., 2003).

These studies suggest that a complete Green Infrastructure may have a considerable potential for improving the health of urban residents. This assertion is based on the speculation that environmentally induced changes in physiological, emotional and cognitive processes may induce, or mediate, changes in well-being and health. Although subjective effects have been found more studies are needed to objectively quantify health benefits from Green Infrastructure. Even those studies with the best controls for socio-economic factors cannot compensate for the array of personal, temporal and cultural factors that also affect human health. Hence, despite accumulating evidence on the relationships between components of the Green Infrastructure and health, causal relationships are not easy to establish. However, sufficient evidence prevails to draw the conclusion that a Green Infrastructure is a significant public health factor (St Leger, 2003; Stokols et al., 2003; Table 2).

6.3. Survey studies

Studies on self-regulation of mood complement epidemiological and experimental studies by emphasising the active role of individuals in the use and choice of green settings. For example, self-report studies on people's favourite places indicate that people visit particular neighbourhood places, mainly natural settings, for regulation of their feelings (Korpela, 1989; Korpela, 1992). In adult samples from different countries, natural places constituted 50–60% of their stated favourite places (Korpela and Hartig, 1996; Korpela et al., 2001; Newell, 1997).

Favourite places afford emotional release and also restorative experiences (Korpela and Hartig, 1996) such as forgetting worries, clearing away random thoughts, recovering attention focus, facing matters on one's mind, and relaxation (Korpela et al., 2001). A decrease in negative feelings and a commensurate increase in positive feelings have characterized visits to natural favourite places in particular (Korpela et al., 2001). Evidence also indicates that adults with high negative mood scores (Korpela, 2003), as well as those reporting a higher incidence of health complaints (Korpela and Ylén, 2006), are more likely to choose favorite places dominated by vegetation than other favorite places, such as sport, commercial or community service settings. Interestingly, some biodiversity (Horwitz et al., 2001) and environmental health (Wilson, 2001) studies have suggested

Table 2
Studies exploring the contributions of green spaces and nature to human health

Author	Type of study	Human health aspect
Kellert and Wilson (1993)	Interdisciplinary studies synthesis	Innate need to be in contact with biodiversity for psychological well-being and personal fulfilment
Takano et al. (2002), Tanaka et al. (1996)	Epidemiological	Urban green space users have greater longevity
de Vries et al. (2003)	Epidemiological	Urban green space users had better self-reported health
Payne et al. (1998)	Questionnaire and diary survey	Urban park users reported better general perceived health, more physical activity and relaxation
Kaplan and Kaplan (1989), Hartig et al. (1991, 2003), Wells (2000)	Experimental	Natural views restore attention fatigue; and quicken recovery of attention-demanding cognitive performances
Ulrich (1984), Ulrich et al. (1991)	Experimental	Natural views provide relaxation, increased positive self-reported emotions, and recovery from stress
Faber-Taylor et al. (2001)	Experimental	Children with attention deficit disorder who are active in green spaces show reduced symptoms
Kuo (2001), Kuo and Sullivan (2001)	Experimental	Green views increase the effectiveness of people in facing major crises, and lessen aggression by reducing mental fatigue
Korpela (1989, 1992), Korpela and Hartig (1996), Korpela et al. (2001), Newell (1997)	Survey	People visit favourite places, often natural settings, for regulation of self-experience and feelings
Kim and Kaplan (2004)	Survey	Natural features and open spaces in a residential area enhance sense of community

that understanding the salutary effects of natural environments (i.e. restorative environments and favourite places in nature), as well as people's attachment to such places, may prove to be important to the study of these phenomena.

6.4. Conceptual models

With the great variety of benefits attributable to Green Infrastructure in relation to the urban ecosystem and human health and well-being, it is not surprising that integrative frameworks have been developed to link human and ecosystem health. One such framework is the human ecosystem framework (Pickett et al., 2001), developed from the human ecosystem model (Pickett et al., 1997), for studying social–ecological systems in urban areas. The human ecosystem framework is an integrated analytical framework for analyzing urban systems as social, biological and physical complexes. The two interconnected parts of this framework are (1) the human-social system – which includes social institutions, social cycles and order; and (2) the resource system – which consists of cultural and socio-economic resources, and ecosystem structure and processes (Pickett et al., 1997, 2001).

The human ecosystem framework was modified with respect to the interactions of ecological and social systems in urban areas by Grimm et al. (2000). This modified scheme highlights the essential variables, interactions and feedbacks connected to land use change (Grimm et al., 2000). Both the original human ecosystem model (Pickett et al., 1997), and the subsequent modified versions (Pickett et al., 2001; Grimm et al., 2000), help in understanding the role of Green Infrastructure in urban areas, and the interactions between Green Infrastructure and urban social systems. However, since these models were developed from socio-ecological considerations, they do not clearly articulate the relationships between ecosystems and public health.

Freeman (1984) suggested a model of environmental effects on mental and physical health. This model stipulates that physical, social and cultural factors, via intermediate vectors, affect the nervous system and this is manifested, via a second set of intermediate vectors, in mental or physical illness. The psychosocial stress and health model was explained in Henwood's (2002) review of the role of environmental and countryside agencies in promoting health. According to this model, environmental stress can lead to chronic anxiety, chronic stress and high blood pressure, with their consequent health implications.

Another integrative framework for factors affecting public health is the arch of health (WHO, 1998). This is a public health model illustrating the environmental, cultural, socio-economic, working and living conditions, community, lifestyle and hereditary factors of public health. Paton et al. (2005), in the healthy living and working model, integrated the arch of health with organisational development principles and systems theory, to promote the settings approach within organisations. The settings approach to public health is characterised by its emphasis on the integration between social, environmental, organisational and personal factors that collectively determine human health and well-being.

The Millennium Ecosystem Assessment was completed in 2005 and assessed global ecosystem changes and their impacts on human well-being. The Millennium Ecosystem Assessment developed a conceptual framework linking ecosystem services and human well-being through socio-economic factors. Thus, ecosystem services were grouped into four categories (provisioning, regulating, supporting and cultural) and human well-being into five categories (security, access to basic resources, health, good social relations and freedom of choice; Millennium Assessment, 2003). Although the well-being categories of the Millennium Ecosystem Assessment Conceptual Framework include broad social and environmental factors, they

Table 3
Models and theories linking ecosystem and human health aspects

Author	Model/theory	Green Infrastructure aspect	Human health aspect
Freeman (1984)	Model of Environmental Effects on Mental and Physical Health	Physical, social and cultural factors	Nervous system and manifested illness
Henwood (2002)	Psychosocial Stress and Health Model	Poor environment	Chronic anxiety, chronic stress and high blood pressure
Pickett et al. (1997, 2001), Grimm et al. (2000)	Human Ecosystem Framework	Ecosystem structure and processes and cultural and socio-economic resources	Socio-ecological systems
WHO (1998)	Arch of Health	Environmental, cultural, socio-economic	Working and living conditions, community, lifestyle and hereditary factors
Paton et al. (2005)	Healthy Living and Working Model	Environmental, cultural, socio-economic	Living and working conditions
Millennium Assessment (2003)	Links between ecosystem services and human well-being	Provisioning, ecosystem services, regulating and cultural	Security, basic resources, health, social relationships, and freedom of choice
Macintyre et al. (2002)	Framework based on basic human needs	Air, water, food, infectious diseases, waste disposal, pollution	Human needs (biological, personal, social, and spiritual)
van Kamp et al. (2003)	Domains of liveability and quality of life	Natural environment, natural resources, landscapes, flora and fauna, green areas	Health all aspects (physical, psychological, social)

do not explicitly distinguish between the biological, psychological and epidemiological aspects of health.

Based on Maslow's hierarchy of human needs, Macintyre et al. (2002) suggested a conceptual framework on which to base measurements of environmental influences on health. The framework suggested by Macintyre et al. (2002) includes various environmental (e.g. clean air and water, and protection from infections), social (e.g. education, and recreation) and economic (e.g. working and transport) factors affecting health, but did not acknowledge the importance of biodiverse habitats in contributing to these factors.

A comprehensive model of liveability and quality of life was synthesised by van Kamp et al. (2003), following their review of the concepts of liveability, environmental quality, quality of life and sustainability. Their model illustrates the complex interplay of factors affecting quality of life including personal, social, cultural, community, natural and built environment, as well as economic factors amongst others (van Kamp et al., 2003). This comprehensive model is useful in conceptualising health determinants, but it does not clearly articulate the links between them. The integrative frameworks linking ecosystem and public health are summarised in Table 3.

7. Conceptual framework linking Green Infrastructure, ecosystem and human health

To summarise the main findings from this literature review and to promote further research in this area, a conceptual framework linking Green Infrastructure, ecosystem and human health and well-being was developed (Fig. 1). The top half of the figure

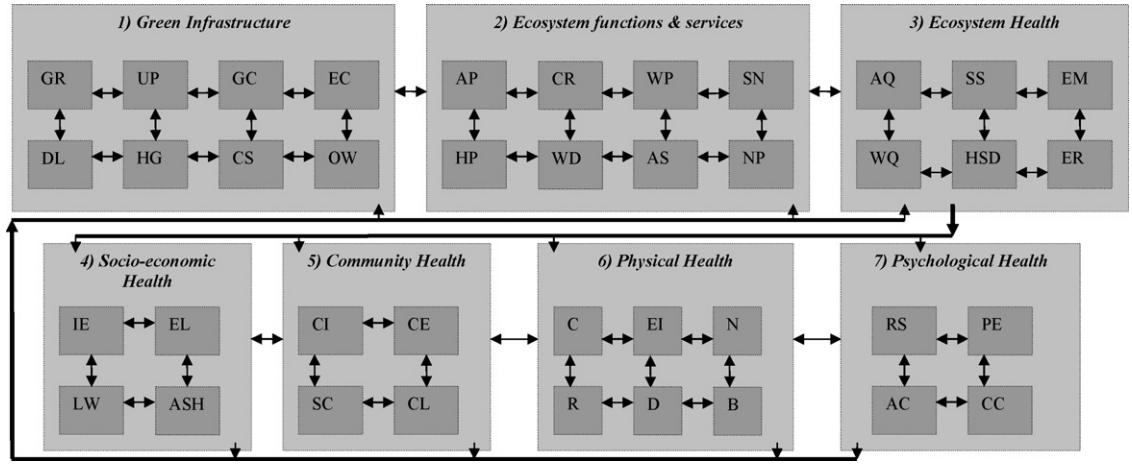

Fig. 1. Conceptual framework integrating Green Infrastructure, ecosystem and human health. The framework has two main parts separated by two-way arrows. The top half (ecosystem) has three interrelated boxes and the bottom half (human health) four interrelated boxes. Two-way arrows indicate two-way interactions. Key: GR: green roofs; UP: urban parks; GC: green corridors; EC: encapsulated countryside; DL: derelict land; HG: housing green space and domestic gardens; CS: churchyards, cemeteries and school grounds; OW: open standing and running water; AP: air purification; CR: climate and radiation regulation; WP: water purification; SN: soil and nutrient cycling; HP: habitat provision; WD: waste decomposition; AS: aesthetic and spiritual; NP: noise pollution control; AQ: air quality; SS: soil structure; EM: energy and material cycling; WQ: water quality; HSD: habitat and species diversity; ER: ecosystem resilience; IE: income and employment; EL: education and lifestyle; LW: living and working conditions; ASH: access to services and housing; CI: sense of community identity; CE: community empowerment; SC: social capital; CL: culture; C: cardiovascular; EI: endocrine functions and immunity; N: nervous system; R: respiratory; D: digestive; B: bone tissue; RS: relaxation from stress; PE: positive emotions; AC: attention capacity; CC: cognitive capacity.

shows the two-way interactions (indicated by two way arrows) between Green Infrastructure, the ecosystem functions and services it provides, and the aspects of ecosystem health that these influence. The Green Infrastructure and associated improvements in ecosystem health provide the environmental settings of public health. These environmental settings contribute to, but are also affected by (two way arrows), aspects of public health which encompass physical, psychological, social and community health. Hence, the lower half of the framework comprises four boxes representing these aspects of health and the two-way interactions between them (two way arrows).

The elements that make up the urban Green Infrastructure are outlined in box 1 of Fig. 1. The typology of urban green spaces developed by the UK's Department for Transport, Local Government and the Regions (2002) has been adopted because it includes green spaces of all types of origin, ownership and function. This typology is inclusive and flexible enough to be applied in a variety of urban settings. Ideally each of these elements should be present in sufficient amounts and interconnected at all scales to create a contiguous Green Infrastructure (Li et al., 2005; Schrijnen, 2000).

In boxes 2 and 3 of Fig. 1, the model of ecosystem health developed by Lu and Li (2003) and the ecosystem services components of the framework developed by Pickett et al. (2001), have been linked with each other and with the Green Infrastructure. Ecosystem health relates to the quality, quantity, configuration and variability of ecosystem functions and services. The Green Infrastructure and its ecosystem functions and services create the urban ecosystem settings within which the socio-economic and other aspects of public health exist.

In the UK, the Indices of Deprivation 2004 (Office of the Deputy Prime Minister, 2004) describe the social, economic and some environmental conditions of communities. These indices formed the basis for the elements included in box 4 of Fig. 1. Furthermore, the healthy living and working model (Paton et al., 2005) and the arch of health (WHO, 1998), also recognise living and working conditions as determinants of public health. Therefore, the residential environment and workplace, as well as educational level and access to health care and other housing facilities, are all important determinants of public health.

Community relationships also contribute significantly to the well-being of individuals (Troyer, 2002; Kuo, 2003; Westphal, 2003). This is why community health has also been included in the conceptual framework (Fig. 1, box 5). Community satisfaction and involvement, as well as community identity, are fundamental to the social well-being of both communities and individuals. The arch of health (WHO, 1998) also recognises culture and lifestyle as determinants of health. Hence lifestyle, community factors and socio-economic factors work synergistically to affect the well-being of individuals.

From the community level of boxes 5 and 6 of Fig. 1, box 6 deals with physical health at the individual level. Epidemiological studies linking Green Infrastructure and health (Takano et al., 2002; Payne et al., 1998) suggest that outdoor or indoor physical activity, if engaged in frequently, also promotes health and well-being (Department of Health, 2004; Sallis and Owen, 1999; Bouchard et al., 1990). Exercise is suggested to have direct health maintenance effects, both preventative and curative (Department of Health, 2004). Therefore, physical health, physical activity and socio-economic and community health are inseparable.

Box 7 (Fig. 1) also focuses at the individual level of health and, in particular, on psychological health. Psychological aspects are considered in relation to contact with green spaces (Hartig et al., 2003; Ulrich et al., 1991; Kaplan and Kaplan, 1989; Kaplan, 1995; Korpela and Hartig, 1996; Korpela et al., 2001; Kuo, 2001). Psychological aspects, including emotional and cognitive elements, are important components of human health. The four boxes in the lower half of Fig. 1 are all interrelated, since they are factors affecting health and well-being of both individuals and communities.

A Green Infrastructure through its ecosystem functions and services creates the environmental settings for community health. The top half of Fig. 1 summarises ecosystem health, with human health aspects summarised in the lower half. Ecosystem management is inevitably guided by human needs, socio-economic factors and cultural conditions. For example, the presence of mosquitoes in a place favoured by the public may result in a demand to use pesticides. Pesticide use may then cause health consequences for the local people (e.g. respiratory irritation) and/or a change in local people's attachment to that place. In turn, this may lead people to select other favourite places (Horwitz et al., 2001). This implies that peoples' health can also be a factor in modifying environments. Therefore, there are two-way interactions between ecosystem and human health, illustrated on the model by two-way arrows between the upper and the lower halves.

The level of resolution of this conceptual framework is that of the landscape scale. This scale is appropriate for the study of ecosystem services and public health. Public health is also represented at both the community level and the individual level. This framework, based on current evidence, does not make assumptions about causality but rather demonstrates the complexity of associations between ecosystems and human health. Mathematical modelling within and between each one of the boxes is feasible by using multivariate analysis of indicators such as habitat size and connectivity, habitat heterogeneity, amounts of pollutants, income, employment, proximity to services, and incidence rates for depression, cardiovascular and respiratory disease. Such a modelling approach could be applied to discern correlations at different scales of resolution. For instance habitat connectivity could be an indicator for Green Infrastructure at the landscape scale, α-diversity could be an indicator at the habitat scale, and particular species of plants could be indicators at the species scale. Additionally, indicators for physical or psychological illnesses could be collected at the national, regional, city and electoral ward levels. Achieving these goals would require the concerted establishment of multidisciplinary international research teams. Multidisciplinary research should be integrated into trans-national research policy if integration between human and ecosystem health is to be successfully achieved.

8. Discussion

This literature review has synthesized research carried out in a number of disciplines which has explored the role of green spaces in public health. Considerable empirical research to explore the roles of environmental factors in public health is needed in order to resolve theoretical and methodological issues before any relevant policy interventions can be formulated. These theoretical and methodological issues include the identification, description and measurement of the environmental processes that affect health; the development and testing of hypotheses to explain how environmental factors influence health; the identification of causal relationships between environmental factors and health; testing of residual confounding variables; undertaking longitudinal studies and ensuring that geographical units (scale) are relevant to the health outcome under investigation (Diez-Roux, 2002). It is also important to distinguish between the compositional, contextual and collective explanations for environmental effects on health (Macintyre et al., 2002).

There is also clearly a need to evaluate the potential economic implications of Green Infrastructure, linked to health effects and health service budgets. In a pioneering study, Bird (2004) developed a model for calculating health care savings attributable to increased outdoor physical activity. Based on a study of five major UK cities, he calculated that if 20% of the population within 2 km of an 8–20 ha green space used that space to reach a target of 30 min activity on 5 days a week, the saving to the UK's National Health Service would be more than £1.8 million (€2.7 million) a year. This finding makes a strong economic case, as well as a strong social case, for enhancing the urban Green Infrastructure for the purpose of reducing health care expenditure.

If the concept of Green Infrastructure is to gain recognition as an important public health factor, it is necessary to articulate the link between ecological and social systems in a way that is understood by those working in different disciplines. The linkages between the Green Infrastructure, ecosystem and human health and well-being presented in this paper provide a basis for such an interdisciplinary "conceptual meeting point". Urban planners, developers, politicians, urban ecologists, atmospheric and soil scientists and social scientists, will be familiar with aspects of the conceptual framework (Fig. 1). Also, public health professionals will not be strangers to issues relating to pollution, and to the issues included in boxes 4 and 6. Community health and psychological health issues are the remit of epidemiologists and environmental psychologists. Thus, this conceptual framework presents opportunities for interdisciplinary collaboration for studying the relationships between the Green Infrastructure and ecosystem and human health.

Neither of the two concepts that are central to the conceptual framework (i.e. ecosystem and human health) can be precisely defined. The concept of human health is defined as an ideal state of socio-economic and biological being (WHO, 1948). Ecosystem health is seen as a heuristic metaphor based on the concept of human health (Haila, 1998). The framework proposed should facilitate interdisciplinary debate to define the conditions of public health and ecosystem health. Ecosystem health indicators based on habitat and species indicators, air and water quality and landscape features and form, can be developed from the top half of the conceptual framework. Public health indicators based on socio-economic derivation, physical illness, death rates, community participation and psychological disorders, can be developed based on the lower half of the conceptual framework. Thus, the conceptual framework (Fig. 1) illustrates possible ways for developing associations between the concepts of Green Infrastructure, ecosystem health and public health. This provides a basis for the establishment of an interdisciplinary approach to urban planning, as has been recommended in a number of studies (Berkes and Folke, 1998; Haeuber and Ringold, 1998; Collins et al., 2000; Devuyst et al., 2001; Kinzig and Grove, 2001; Ehrlich, 2002).

The interdisciplinary nature, and the detail, of this framework are its main strengths. In particular the level of detail is purposefully designed so that it might be used flexibly and adjusted to particular settings. Another strength of the framework is that it does not distinguish between what is considered to be more or less important, or between primary and secondary factors and their relationships. This allows for debate and dialogue between disciplines. It also allows for changing scientific evidence and changing social and political values to be incorporated into discussions without the whole framework having to be redesigned. The framework does not explicitly distinguish between scales but rather recognizes interacting themes that might be scale independent, and on to which political or biological boundaries may be imposed if this is required.

The integrative conceptual framework that is proposed here contributes to the settings approach to public health by incorporating the arch of health (WHO, 1998) into the discipline of urban ecology. In addition, the proposed framework elaborates the findings of the Millennium Assessment (2003) and emphasized their applicability to the urban context. This is an important consideration in the light of ongoing expansion and intensification of urbanisation worldwide. Most importantly, this new conceptual framework illustrates clearly the relationships between ecosystem and human health systems, thus providing an outline for creating an interdisciplinary research agenda within which hypotheses can be developed, and progress made, in measuring and modelling the role of Green Infrastructure and ecosystem health in maintenance of human health.

9. Conclusion

Ecosystem services provided by a Green Infrastructure can provide healthy environments and physical and psychological health benefits to the people residing within them. Healthy environments can contribute to improved socio-economic benefits for those communities as well. The hope and intension of this paper is to encourage the integration of information among and between the various disciplines such as the urban nature conservationists, environmental psychologists, and public health specialists to further improve urban and peri-urban environments.

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