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REVIEW

Linking ecosystem services and human health: the Eco-Health Relationship Browser

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Abstract
Objectives Ecosystems provide multiple services, many of which are linked to positive health outcomes. Review objectives were to identify the set of literature related to this research topic, and to design an interactive, web-based tool highlighting the weight of evidence, thus making the information more accessible.
Methods A systematic review was conducted to create the Eco-Health Relationship Browser (http://www.epa.gov/research/healthscience/browser/introduction.html). The search was conducted in four stages utilizing Google Scholar, PubMed and Science Direct, targeted journals, and targeted keywords; search results were limited to peer-reviewed journal articles published in English from 1 January 1990 to 31 December 2012.
Results The review identified 344 relevant articles; a subset of 169 articles was included in the Browser. Articles retrieved during the search focused on the buffering and health-promotional aspects of ecosystem services. Landscape and Urban Planning, Urban Forestry and Urban Greening, and Health and Place yielded the most articles relevant to this search.
Conclusions Results from the systematic review were used to populate the Browser, which organizes the diverse literature and allows users to visualize the numerous connections between ecosystem services and human health.

Keywords Human health · Ecosystem services · Green space · Systematic review · Urban ecosystem · Well-being

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Introduction

Ecosystems provide many nature-based goods and services that are beneficial to society. According to the Millennium Ecosystem Assessment (2005), ecosystems supply food, water, fuel, and fiber (provisioning services); help regulate climate, floods, disease, and air and water quality (regulating services); provide recreational and aesthetic benefits (cultural services); and promote processes such as photosynthesis and nutrient cycling (supporting services). Despite increasing isolation from the natural world, society is nonetheless fundamentally dependent on the flow of ecosystem services (MEA 2005).

The provisioning services of nature are largely self-evident. Previous research has addressed regulating services, including the filtration of air pollutants such as PM, ozone, NO_x, and SO_2 by trees and other greenery (Bealey et al. 2006; Escobedo and Nowak 2009), heat mitigation by green spaces such as parks and urban forests (Solecki et al. 2005; Jim and Chen 2009), and water regulation by wetlands (Ming et al. 2007). Several reviews have also summarized regulating nature-based services such as air filtration and carbon sequestration by forests (Karjalainen et al. 2010), water filtration and regulation by wetlands (Horwitz and Finlayson 2011), and water and climate

regulation by agricultural ecosystems (Swinton et al. 2007). In addition to this regulation, which provides a buffer from pollutants and natural hazards, ecosystems can also promote healthy behaviors by creating opportunities for physical activity and social interaction.

Ecosystem services and human health

There is a large body of research linking ecosystem services to improvements in human health. The ecosystem services that are most relevant to human health can be broadly categorized: air filtration; biodiversity conservation; climate stabilization; habitat maintenance; natural hazard mitigation; food, fuel and fiber production; water filtration; water regulation; and the provision of aesthetic environments and recreational opportunities. Though a variety of studies investigate the linkages between ecosystem services and human health, a majority of the recent research focuses on the psychological and physiological effects of green space. Green space is defined by the US Centers for Disease Control and Prevention (CDC) as open, undeveloped land with natural vegetation, such as yards, parks, and trails (CDC 2011).

A seminal study by Ulrich (1984) reported improved recovery time for post-operative patients who had a view of natural settings from their hospital rooms compared to matched patients who were in similar rooms but with a view of a brick wall. The field has expanded considerably since this work, falling into the purview of several disciplines. Recent research has reported the impact of residential tree cover and green space on birth outcomes (Donovan et al. 2011; Dadvand et al. 2012), overall mortality (Villeneuve et al. 2012), morbidity (Maas et al. 2009), and senior longevity (Takano et al. 2002). The risk of heat-related illness among the elderly was lower in cities with a higher percentage of green space (Zanobetti et al. 2012). The presence of street trees was associated with lower prevalence of early childhood asthma (Lovasi et al. 2008). Green activity, defined as physical activity taking place in a natural setting, has also received recent attention and has been linked to the improved self-esteem and mood (Barton and Pretty 2010; van den Berg et al. 2010) as well as enhanced concentration and cognitive performance (Hartig 2008). Physical and visual access to green space was also linked to improvements in mental health and restoration (Hartig et al. 2003; Pretty et al. 2005), a reduction in stress (Park et al. 2008; Thompson Coon et al. 2011), and improved cognitive function and directed attention (Kuo and Faber Taylor 2004; Faber Taylor and Kuo 2009). A recent review by Bratman et al. (2012) focused on the positive impacts of nature on cognitive function and mental health, as well as prevailing mechanistic theories and biologically plausible exposure pathways.

Several reviews have introduced new conceptual frameworks to aid in organizing this set of literature. One such review highlighted the connections between exposure to green space and health outcomes (Lee and Maheswaran 2011); another focused on plausible causal pathways and raised important concerns about the role of potential moderating and mediating factors such as socioeconomic status and individual perceptions of the environment (Lachowycz and Jones 2012). Tzoulas et al. (2007) summarized the connections between green infrastructure, ecosystem health, and human health. Nonetheless, there remains a need to further synthesize the ever-expanding set of literature to make available information accessible to a broader audience, particularly policy makers (Bowler et al. 2010).

We conducted a systematic review focused specifically on the linkages between buffering and health promotional ecosystem services and human health. While provisioning services are conceptually important, they were not the focus of this review. We sought to organize the literature into an interactive, web-based tool: the Eco-Health Relationship Browser (the Browser), which is hosted on the US Environmental Protection Agency website (http://www.epa.gov/research/healthscience/browser/introduction.html).

In creating the Browser, our primary objective was to highlight the linkages among ecosystems, ecosystem services, and human health. We had two parallel goals: first, to synthesize the emerging literature and second, to create a web-based tool that would make the literature accessible to a diverse audience. The Browser is a careful selection of evidence intended to provide information about ecosystems, the services they provide, and how those services are associated with human health. It was designed as an educational tool that allows the user to easily explore the complex interactions evident in the literature. While many references included in the Browser do not document causal relationships, they were chosen to demonstrate possible and plausible associations.

Methods

Systematic review

We conducted a systematic review to identify the existing literature related to ecosystems and human health. In particular, we focused on the health benefits associated with ecosystem services. The search was limited to peer-reviewed journal articles published from 1 January 1990 to 31 December 2012. English language articles gathered during the four-stage search process (Fig. 1) were imported into and organized in EndNote (Thomson Reuters, X5). Rather than collect duplicate articles throughout the

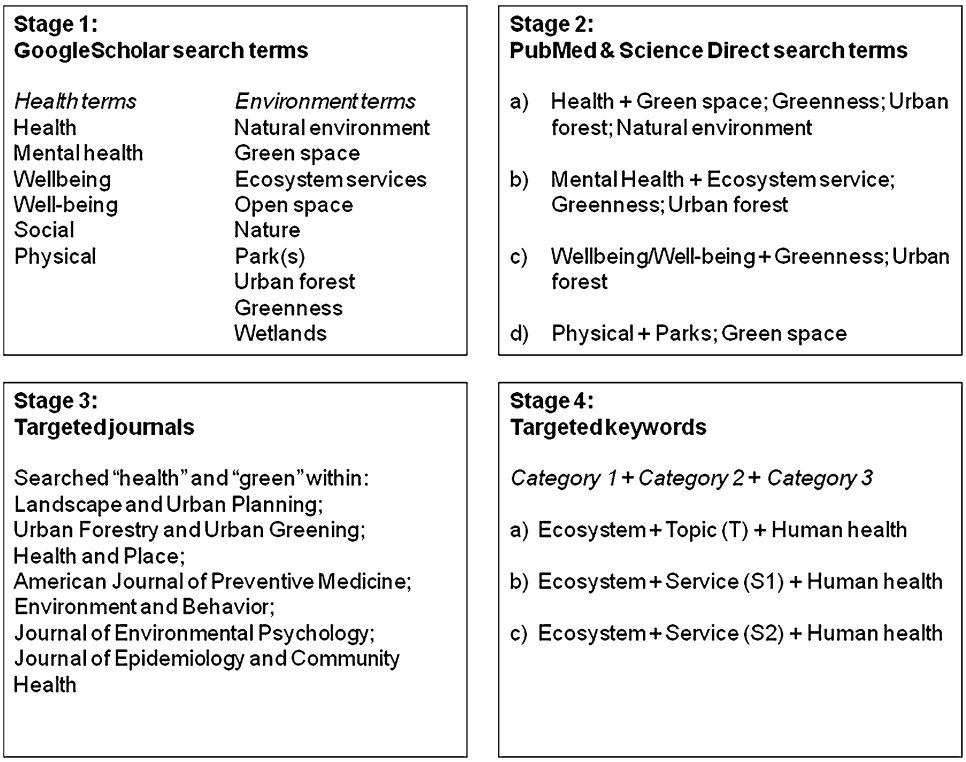

Fig. 1 The four stages of the systematic review

review, those articles that had been found in the search previously were not imported again. All titles and abstracts were reviewed for relevance, and potentially relevant studies retrieved during the search were collected in EndNote for further review.

Stage 1: Google Scholar

Google Scholar was searched using Boolean phrases that contained at least one health keyword and at least one environment keyword. The first 30 non-duplicative articles from each search were reviewed for relevance (Fig. 1, Stage 1).

Stage 2: PubMed and ScienceDirect

PubMed and ScienceDirect databases were searched using the 13 most successful combinations of Boolean phrases from the previous Google Scholar search. Combinations were deemed successful if they returned more than 10 applicable articles in the initial search. In ScienceDirect, search terms were limited to the Abstract, Title, and Keywords. In PubMed, search terms were limited to the Title and Abstract as there was no Keywords option. The first 50 non-duplicative articles from each pairwise search were reviewed for relevance (Fig. 1, Stage 2).

Stage 3: targeted journals

Journals returning more than five applicable articles in the previous two stages were targeted (Fig. 1, Stage 3). The term "green" was searched in predominately health-focused journals, and the term "health" was searched in environment-focused journals. The first 50 non-duplicative articles were reviewed for relevance. In cases where the journal was not clearly delineated as health- or environment-related (e.g., Journal of Environmental Psychology), both search terms were used. Furthermore, issues published in 2011 and 2012 in these targeted journals were screened for additional relevant articles that had not yet been identified in the search. At this time, reference lists from newly identified studies were also hand screened for additional relevant articles.

Stage 4: targeted keywords

In briefly reviewing the collected articles from the previous three stages, it was apparent that the original search terms were too broad to capture some of the known literature related to specific ecosystem services and human health. For this reason, a more in-depth search using targeted ecosystem services-related keywords was conducted (Table 1; Fig. 1, Stage 4). All unique combinations of the three search-term categories were used; this includes one

Table 1 Search terms used in Stage 4 of the systematic review, the targeted keyword search of peer-reviewed articles from 1990 to 2012. All unique combinations of the three categories were included

Ecosystem service	Category 1 Ecosystem	Category 2 Topic (T)/Service (S1, S2)	Category 3 Health
Air filtration	Forest	Air pollution (T)	Human health
	Urban	Air pollution removal (S1)	
		Air filtration (S2)	
Water filtration	Forest	Water contamination (T)	Human health
	Urban	Water contaminant removal (S1)	
	Agricultural	Water filtration (S2)	
	Wetland		
Water regulation	Wetland	Water flow (T)	Human health
	Urban	Water storage (S1)	
	Forest	Water regulation (S2)	
Engagement with nature	Wetland	Nature interaction (T)	Human health
	Urban	Natural environment (S1)	
	Forest	Engagement with nature (S2)	
	Agricultural		
Promotion of physical activity	Forest	Recreation (T)	Human health
	Urban	Physical activity (S1)	

topic and up to two ways of describing the ecosystem service. The first 30 non-duplicative articles from each combination were reviewed for relevance.

The original search was completed in March, 2012. Stages 3 and 4 were repeated to update the search through 31 December 2012.

Screening articles for the Browser

The Browser is composed of three tiers of information relating to ecosystems, ecosystem services, and health outcomes. The articles collected from the systematic review were synthesized and cited in Browser pop-up windows based on where they fit within the pre-defined structure of the tool, either linking ecosystems and ecosystem services or ecosystem services and health outcomes.

Articles gathered as part of the literature review were screened for inclusion in the Browser based on the following criteria: articles had to include ecosystem services/natural stimuli/exposure to nature as one of the study parameters and also had to include a measurable health outcome or relate to overall health. Articles were also retained if they addressed how ecosystems or their components buffer against hazards known to have adverse health impacts. The main reasons for article exclusion were inappropriate article type (e.g., book, abstract), no reported consideration of ecosystem services/natural stimuli/nature as the exposure variable, no mention of a health outcome, or lack of adherence to Browser structure (e.g., review papers). In addition to overall relevance, articles were also evaluated on study design (e.g., objective measure, self-report, survey) and presentation of results (e.g., quantitative findings, direction of association, strength of relationship).

In synthesizing the literature for the Browser, preference was given to articles that were published after 2000, with objectively measured variables and quantitative results. For example, considering the topic of green space and stress, the highest priority was given to studies using objective measures of stress such as cortisol levels (Lee et al. 2011), followed by a standardized technique such as the Zuckerman's Inventory of Personal Reactions (ZIPERS), Overall Happiness Scale (OHS), or the Necker Cube Patter Control Task (NCPCT) (Hartig et al. 2003), and finally, self-reported feelings of mood and restoration (Cole and Hall 2010). For topics that had few or no quantitative results, qualitative evidence of the observed relationship was reported. The number of articles cited in the pop-up summaries is indicative of the weight of evidence surrounding that topic. Those articles not prioritized for the pop-up window summaries were still included in the Browser bibliography.

Results

Systematic review

From the systematic review, 344 potentially relevant articles cited in 145 journals were collected for further review (Fig. 2). Several of these journals published multiple articles directly related to ecosystem services and human health; between 4 and 17 articles were found in 12 journals (Table 2). Results from this literature search suggest an

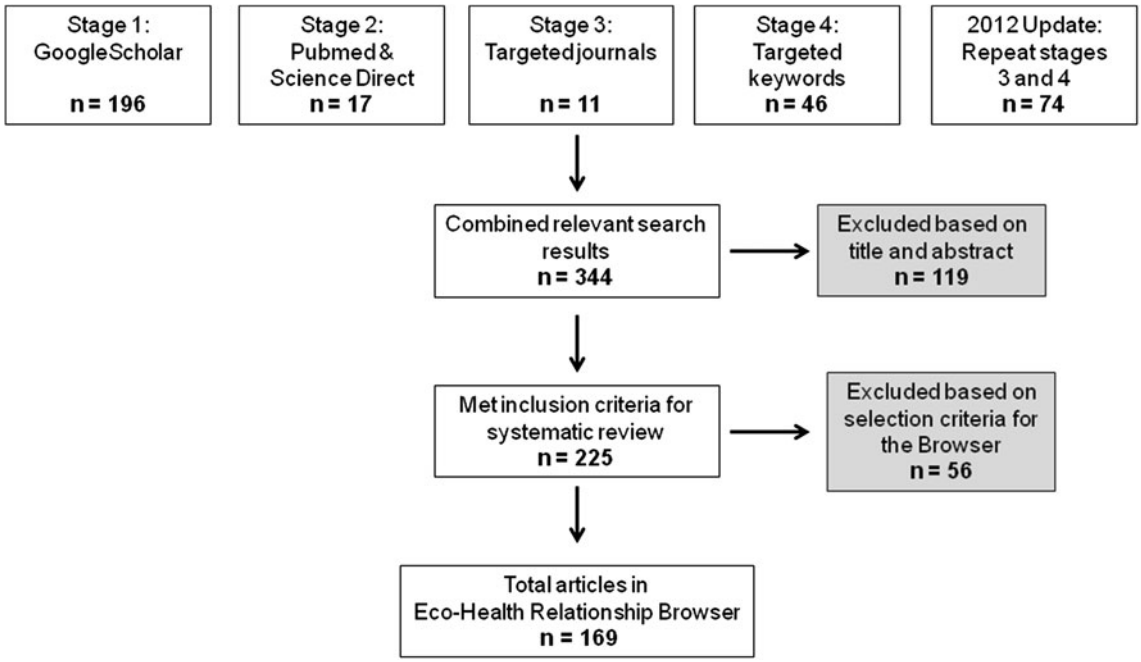

Fig. 2 Search results from the systematic review and screening for The Eco-Health Relationship Browser

Table 2 Journals publishing relevant articles identified in the systematic review of ecosystem services and human health from 1990 to 2012

Journal	Number of articles
Landscape and Urban Planning*	17
Urban Forestry and Urban Greening*	15
Health and Place*	13
Environment and Behavior*	12
Journal of Environmental Psychology*	7
American Journal of Preventive Medicine*	6
Journal of Epidemiology and Community*	6
Preventive Medicine	5
American Journal of Public Health	4
BMC Public Health	4
Environmental Health and Preventive Medicine	4
Public Health	4

* Indicates journal was included in Stage 3 of systematic review

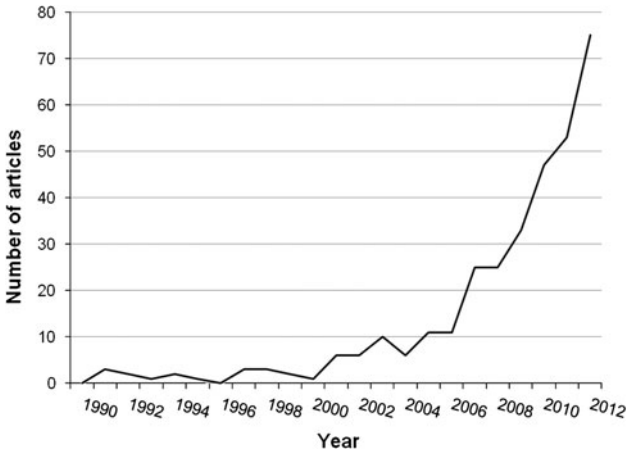

Fig. 3 Number of relevant articles returned from the systematic review from 1990 to 2012

increase in attention to this subject area, as the annual publication of articles increased substantially from 0 to 75 from 1990 to 2012 (Fig. 3).

During the review process, articles focused on the buffering or health-promotional aspects of ecosystem services were identified. For example, several articles addressed the ability of tree cover to act as a buffer against adverse health effects, such as increased risk of bronchitis, asthma, and other respiratory diseases (Bayer-Oglesby et al. 2005), by filtering and adsorbing multiple air pollutants (Nowak et al. 2006; Escobedo and Nowak 2009; Pullman 2009). Health-promotional services, such as the opportunity for physical activity and engagement with nature, were the most common ecosystem services reported. Several gaps in the literature were evident as no articles focused on the direct link between water filtration and improved health outcomes. Interestingly, few articles on heat mitigation and health were identified, which may be due to the fact that heat mitigation literature is often associated with climate change research and does not have as strong a connection to ecosystem services research.

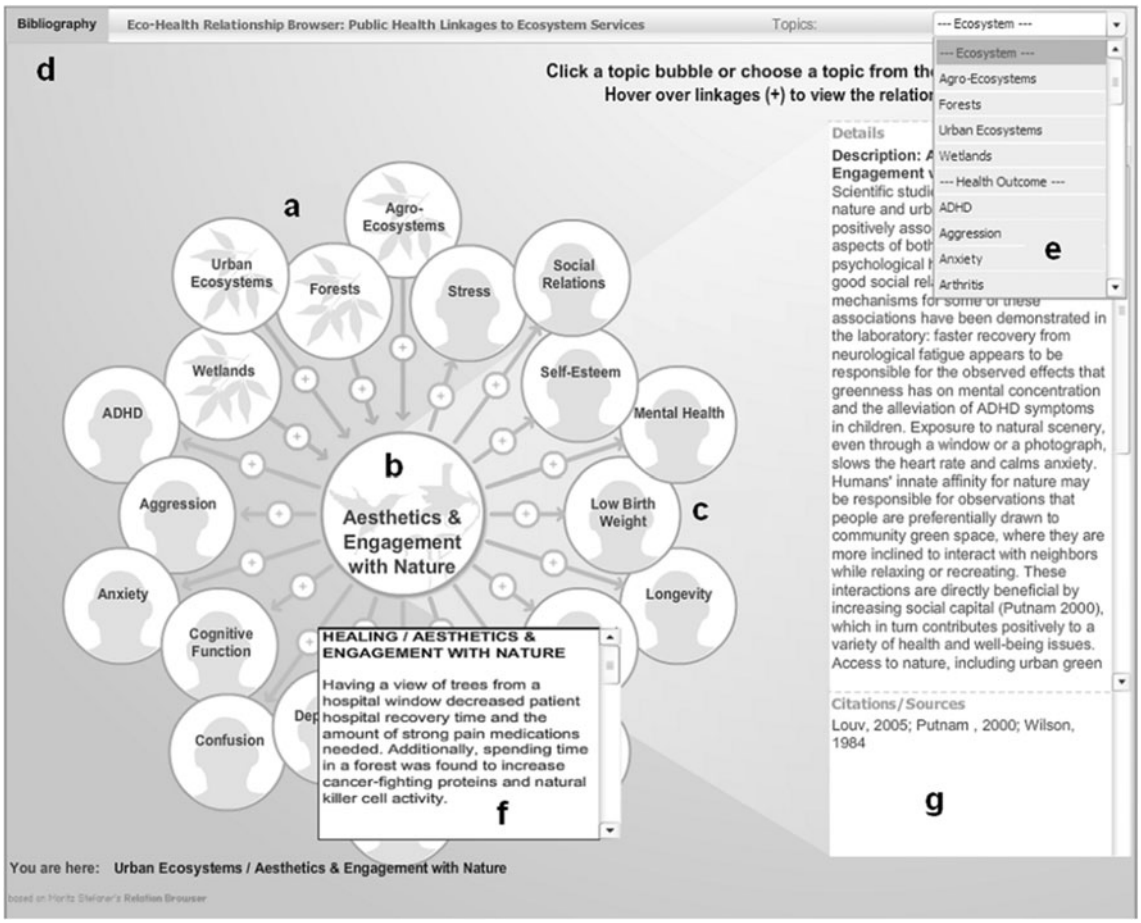

Fig. 4 A screen capture of the Browser illustrating the three main components **a** ecosystems, **b** ecosystem services, and **c** health outcomes, as well as the **d** bibliography, **e** drop down menu, **f** pop-up summaries, and **g** sidebar descriptions

The Browser

Structurally, the Browser is composed of three tiers: four ecosystems (agricultural, forest, urban, and wetland), six ecosystem services (clean air, clean water, aesthetics and engagement with nature, heat hazard mitigation, water hazard mitigation, and recreation and physical activity), and multiple health outcomes (Fig. 4). The Browser also contains an introductory page, a bibliography, and sidebar descriptions intended to provide additional information about each topic. Sidebar citations include peer-reviewed literature as well as links to relevant websites such as the World Health Organization and CDC. A pop-up function over the "+" symbols elaborates on the association between the two linked components. Each pop-up box contains summaries of selected articles, along with citations, the sample size, and the study location. With condensed citations and important summary information, the pop-up windows are intended to capture the current state of the science. Since the topic of nature's role in human health is still an emerging field, these summaries can assist the reader in distinguishing between speculative and more well-established results.

From the 344 articles identified in the literature review, 169 were included in the Browser. The screening process resulted in 70 articles relating ecosystems to ecosystem services and 131 articles linking ecosystem services to health outcomes; some articles fit in both categories. Articles that were applicable, but did not fit into the pre-defined structure of the Browser (e.g., reviews) were excluded from the pop-up summaries, but were included in the bibliography. The bibliography captures all of the salient findings from the systematic review.

Discussion

This paper presents the results of a systematic review and the development of an interactive, web-based tool. The primary objective was to make the information obtained from this review available and accessible to a wide user base. The Browser is intended to capture the weight of

evidence on the topic of ecosystem services and human health and to highlight observed associations so that users understand the connections between ecosystems and health. This area of research includes the fields of ecology, environmental science, urban planning, public health, and sustainable development. These fields have converged in their efforts to investigate the impact of the physical environment, including both built and natural components, on human health and well-being.

The focus of this review was the link between ecosystems, ecosystem services, and human health—not the stressors on these systems. For that reason, articles that may have focused on air pollution and health but did not mention an ecosystem, such as a forest, or the service of air filtration, were not retrieved as part of the search. However, to demonstrate the importance of buffering services, representative studies summarizing the association between environmental stressors and adverse health outcomes were included in the Browser. Reviews were not included in the summary pop-up windows as they did not meet the inclusion criteria of reporting unique findings from primary sources; our intention was not to summarize summaries. However, a majority of the original articles summarized in the reviews were retrieved separately during the systematic review and are included in the Browser. Recognizing the usefulness of review articles on this topic, we included all relevant reviews in the Browser bibliography.

The bulk of articles retrieved during this systematic review can be described as either buffering or health-promotional services, which are akin to the regulating and cultural services outlined in the Millennium Ecosystem Assessment (MEA 2005). For example, ecosystem services such as air and water filtration, heat mitigation, and water regulation act as buffers against potential environmental pollutants and other health hazards. Ecosystem services such as the opportunity for physical activity and engagement with nature can promote healthy behaviors; these services have been linked to a broad range of improved health outcomes, including reductions in stress and blood pressure (Hartig et al. 2003) and improvements in cognitive function (Kuo and Faber Taylor 2004; Pretty et al. 2005).

Where parks and other green infrastructure provide opportunities for physical activity, the causal pathway is well established. Beyond "green" exercise, most of the research on the health promotional aspects of engaging with nature is associative at this time. Prevailing theories on the underlying mechanisms linking engagement with nature to improved health outcomes can be summarized as follows: (1) the stress reduction theory, first proposed by Ulrich (1983), emphasizes a reduction in stress while experiencing natural stimuli as measured by physiological responses; (2) the attention restoration theory, first proposed by Kaplan and Kaplan (1989), focuses on recovery from directed attention fatigue through experience of natural stimuli as measured by cognitive responses; (3) the opinions on nature theory discussed by Bratman et al. (2012) states that an individual's preferences for nature can affect the degree of restorative benefits on mood and cognitive function; and (4) the social cohesion theory attributes improvements in mental health following both physical activity and exposure to nature to increased social interaction (Maas et al. 2008; Barton and Pretty 2010). While these theories introduce potential underlying mechanisms, questions regarding the exact biological pathways linking exposure to nature with improved health outcomes require additional research. Does green space encourage physical activity? Does green space encourage social interaction? Does exposure to nature trigger a more innate or evolutionary response, supporting the Biophilia Hypothesis introduced by Kellert and Wilson (1993)? Are two or more of these mechanisms operating in tandem?

In a recent review of the theoretical relationships between access to green space and health, Lachowycz and Jones (2012) assert that, without robust conceptual models to support hypothesis generation and study design, research will be limited in its ability to confirm potential causal pathways. While most work presents a general association, a review by Lee and Maheswaran (2011) concludes that establishing a causal link is difficult. In many cases, the literature also includes findings of no association between the surrounding environment and health. In a systematic review examining associations between access to green space and physical activity, evidence was mixed (Lachowycz and Jones 2012). Additional studies have found no correlation between green space and child obesity rates (Potestio et al. 2009), or cardiovascular disease mortality in New Zealand (Richardson et al. 2010).

Part of the challenge in establishing a causal link between health-promotional ecosystem services and human health is the potential for unmeasured confounding variables to bias results. Lachowycz and Jones (2012) suggest three potential confounding factors to consider when evaluating potential associations: (1) use of green space as distinct from proximity—time constraints, access to transportation, and pre-existing health conditions are examples of variables that may limit use of proximate resources; (2) motivation to use green space—influenced by personal factors such as daily routines, perceptions of the environment, and access to alternative health promotional resources; and (3) local environment—conditions such as weather, light, and traffic can influence use of green space. In addition, Davison and Lawson (2006) suggest that use of green space among children is substantially moderated by parental attitudes about safety. The presence of physical barriers such as major roads and highways (Lee and Moudon 2008), as well as fences, can also affect use.

Research also suggests that different demographic groups value different aspects of green space; these values can influence individual choices and behavior related to use (Cohen et al. 2009; McCormack et al. 2010). Interventions focused solely on increasing the amount of green space without consideration of these potential social and environmental barriers to use will fail to provide the health-promotional benefits associated with natural resources (Lee and Maheswaran 2011).

Although the goal of this systematic review was to highlight a specific subject matter—the links between ecosystem services and human health—the primary limitation of this study is its exclusion of relevant studies related to the built environment. In addition to characteristics of the natural landscape, neighborhood connectivity and land-use mix are important characteristics of the built environment that can affect physical activity and engagement with nature (Saelens and Handy 2008). The built environment has been linked to the likelihood of physical activity and adverse health outcomes such as obesity and impaired mental health (Ewing et al. 2003). Design of the built environment can significantly affect access to green space, opportunities for physical activity and engagement with nature, and overall health and well-being (Jackson 2003).

Conclusions

Human health depends on a number of factors, and there is now a substantial weight of evidence suggesting the important role of ecosystem services. The Eco-Health Relationship Browser organizes a diverse set of literature and helps the user to visualize the numerous connections. We encourage the design of similar interactive tools to make complementary data related to the built environment accessible to a broader audience. The Browser can help users to identify the extent to which ecosystem services are associated with health outcomes, and has the potential to help practitioners and decision makers to better understand the synergistic benefits of healthy and functioning ecosystems. It is important to understand that the loss or degradation of ecosystems and ecosystem services may contribute to cumulative burdens on population health. Findings from this review have made clear that future research should be designed with potential biologically plausible pathways in mind. With the goal of promoting healthy living in the context of healthy environments, sufficient attention must be paid to the interactions between ecological, social, and environmental systems as well as issues of access and environmental justice.

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Conflict of interest The authors declare that they have no conflicts of interest.

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