Shades of Green: Measuring the Ecology of Urban Green Space in the Context of Human Health and Well-Being

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ABSTRACT
In this paper we review and analyze the recent research literature on urban green space and human health and well-being, with an emphasis on studies that attempt to measure biodiversity and other green space concepts relevant to urban ecological restoration. We first conduct a broad scale assessment of the literature to identify typologies of urban green space and human health and well-being measures, and use a research mapping exercise to detect research priorities and gaps. We then provide a more in-depth assessment of selected studies that use diverse and innovative approaches to measuring the more ecological aspects of urban green space and we evaluate the utility of these approaches in developing urban restoration principles and practices that are responsive to both human and ecological values.

KEYWORDS
biodiversity, green infrastructure, proxy measures, research mapping, scenario manipulation, urban ecological restoration

Western ideas about the benefits of nature to human health and well-being go back at least two centuries, but until the emergence of landscape perception and assessment research in the 1960s these benefits were considered too subjective to measure. Kaplan et al. (1972) were among the first to measure people's preferences for natural over urban scenes, and before long investigators were developing models to predict green space preferences based upon the biophysical, psychological, and artistic properties of vegetation and other landscape elements (Daniel 2001). These included psycho-evolutionary models that suggested that humans prefer savanna-like landscapes characterized by open glades with smooth ground texture, framed by clumps of mature trees (e.g., Ulrich 1986), and that vegetation types associated with more biodiverse landscapes such as rough ground cover, woodland edge, or scrub were generally lower in preference (Parsons 1995). Nassauer's (1995) work, suggesting that preferences for "messy ecosystems" could be enhanced by placing landscapes within "orderly frames,"

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helped to move the discussion on beyond the relative merits of scenic as opposed to ecological aesthetics.

Research on urban green spaces and human health and well-being has steadily expanded beyond its original focus on landscape preference, and social scientists and public health researchers have been studying how various aspects of human health and well-being are affected by exposure to green spaces (e.g., Bell et al. 2008; Maller et al. 2002; Tzoulas et al. 2007). While the scope of this research has been diverse, the main focus has been on the human side of the equation, to understand the benefits and outcomes that green space has for people measured at psychological, social, and physiological levels of concern. The green side of the equation—the measurement of green space qualities and characteristics—has sometimes also been an important part of this work, but many questions remain about the nature of green space as it relates to human health and well-being (Frumkin 2001, 2006; Velarde et al. 2007). What are the key green space characteristics that generate desired health and well-being outcomes? Do different characteristics of “green” play differential roles with respect to various human benefits? How can an enhanced understanding of these characteristics and their beneficial properties be integrated with other contemporary green space agendas including ecological restoration and the creation of multifunctional green infrastructure?

In this paper we take a first step in addressing these questions by examining how researchers have measured predominantly urban green space in the context of human health and well-being with reference to a broad spectrum of urban green spaces, but especially the more structurally complex and biodiverse natural environments associated with ecological restoration. Our approach relies on an assessment of recent research literature, classifying the types of green space measures that are being used and mapping them with measures of human health and well-being also under consideration.

As well as mapping the green space measures against human health and wellbeing outcomes, we go on to consider how effective these measures are in the context of an inter-disciplinary research context. Green space—open land and its vegetative cover[1]—forms the central part of urban ecosystems. To enhance the function and sustainability of urban ecosystems, ecologists and land managers argue that green space must be more than the mown grass and ornamental tree plantings that typifies managed green space in most cities. But while restoration provides a set of principles and practices for increasing the ecological values of urban green space, those involved in urban ecological restoration are becoming increasingly aware of the need to also take into account its social values, including the health and well-being dimension (e.g., Ingram 2008). At the same time, there has been a growing focus on the ecological health of urban systems more generally, and researchers in urban ecology, urban ecological restoration, and other fields have developed concepts and practices for measuring and managing urban land cover to maintain hydrological function, promote air quality, regulate microclimate, sequester carbon, and preserve species and habitat diversity (Nowak and Dwyer 2007; see also Del Tredici this issue). A major obstacle connecting these two lines of research has been the lack of suitable metrics to measure the characteristics of green spaces against the full range of desired human and ecological benefits (e.g., Fry et al. 2009). If urban environments are to deliver the fullest possible range of benefits, it is essential that relevant and meaningful green space measures be found.

Within this problem context, the questions this paper seeks to answer are:

1. How is urban green space conceptualized and measured in research directed at human health and well-being?
2. How does the use of green space concepts and measures vary according to the particular human benefit and outcome measures under consideration?

While these two questions relate most directly to the quantitative "data" portion of our study and provide a broad picture of the current state of research, a subset of this work is then examined at greater depth in a more qualitative way to address the following questions:

3. Which of these approaches have the greatest potential to be used in interdisciplinary research linking the social and natural sciences and urban ecological restoration planning and management?
4. What issues need to be overcome in developing holistic and transferable conceptualizations of urban green space?

Methods

Our literature review and assessment draws upon a sample of recently published studies on urban green space and human health and well-being relationships. As described earlier, urban green spaces provide many human and environmental benefits, and a recent review by Bell et al. (2007) divided this literature into five broad categories: health and well-being, social and community, economic values, environmental quality, and planning and design (including perceptions and preferences). While the economic and environmental aspects are clearly crucial in building a more holistic view of human-green space relationships, the other three categories identified by Bell et al. seemed to capture the appropriate breadth of literature for our focus.

We developed a three-step strategy to identify the study sample. First, we conducted an electronic search of the literature using the Scopus database. After some trial and error, we developed the following query: "(TITLE-ABS-KEY(biodiversity OR greenspace* OR "green space*") AND TITLE-ABS-KEY(urban) AND TITLE-ABS-KEY(health OR well-being))," and limited the search to articles published in journals after 1997. This generated a total of 189 items. Our original intention was to repeat the Scopus search for the "social and community" and "planning and design" categories of Bell et al.'s (2007) classification, but this strategy soon proved unsatisfactory. Not only did each iteration of the search generate an unmanageably large quantity of new literature, but we also found that some key studies we knew of were not being retrieved.

Therefore, as a second step in identifying our sample we adopted a more purposive approach. We began by assembling a collection of literature we already knew about and then supplemented it by using "snowballing" techniques such as scanning reference lists of articles for promising citations. This yielded an additional 241 publications.

The final step in identifying a sample of the literature for further analysis was to screen the set of 430 publications for those that conformed to our specific study objectives. We entered study citations and abstracts into a spreadsheet and coded the articles for key information. We then eliminated from further analysis any articles that were not applicable to urban green space issues, were not empirical, were not published in refereed journals, or did not have measures of green space or human benefits sufficiently well described or central to our own work, leaving a final sample of 182 items. While this semi-systematic procedure no doubt missed some articles, we felt confident that the resulting sample of 182 articles used in our final analysis provided a good cross-section of the literature as well as a number of key articles.[2]

To address research questions 1 and 2 of our study, we developed initial taxonomies for classifying green space and human health and well-being measures. We each read a portion of the sample studies and for each paper wrote a short description of its green space and human measures along with coding classification. We then discussed the coding and adjusted our taxonomies until we felt comfortable that they were meaningful and could be used consistently. These taxonomies are set out in Tables 1 and 2. To help make sense of the find-

Table 1 ■ Taxonomy of green space measures

Code	*Definition*
None	Green space is the focus of study but no attempt is made to measure, vary, or describe its characteristics.
Urban versus natural	Research design compares exposure to urban and natural settings
Descriptive/ narrative	Qualitative description of green space by research participant without categorization.
Inventory	Multiple environmental characteristics including vegetation and facilities, many not relating to urban green space.
Area/Distance	Quantity or proximity of green space, usually with reference to research participants' homes. Objective measure or self-report.
Biophysical	Presence/quantity of specific landscape elements (e.g. vegetation, % open land) or interventions with different landscape outcomes (e.g. forest management plans). Covers most physical measures falling short of biodiversity. Objective and/or self-report. May be inherent in the stimulus (e.g. % vegetation manipulated in the research design) or explicit in the measure (e.g. vegetation density within a given area).
Human perceptual	Categorizations based on cultural constructs/ descriptors/values (e.g., quality of green space, naturalness (unless linked to a biodiversity measure), openness). Landscape types. May be inherent in the stimulus or explicit in the measure or both. Objective measure or self-report.
Biodiversity	Objective measure of plant/animal diversity (or close proxy), or where the concept of "biodiversity" is being evaluated.

Table 2 ■ Taxonomy of human health and well-being measures

Code	*Definition*
Preference	Participants are asked to rate the attractiveness of different landscape scenes or scenarios, or their suitability for a particular activity
Attitudes, meanings, and values	Spans a range of methodologies from quantitative, in which participants are asked for their level of agreement with attitudinal statements, to qualitative approaches, in which underlying meanings and values are explored.
Psychological benefits	Self-rated or objectively measured psychological health or other psychological measure including restoration and affective responses to landscape.
Physical health	Self-rated or objectively measured physical health.
Behavior	Behavioral patterns or changes e.g. physical activity, walking.
Mixed	Several human measures. No overall focus on one aspect.
Other	Other human measure (e.g. socio-economic variables)

ings from this taxonomic coding, we used a variant of the research mapping process described by Bell et al. (2007). For this process, coding information for the studies was tabulated in a green space-by-human benefit matrix. According to Bell et al., examining the distribution of studies across the various cells of the matrix can help reveal research priorities and gaps.

To address research questions 3 and 4, we jointly selected 30 studies from among the 182 that we felt represented diverse and innovative approaches to measuring the more ecological aspects of urban green space and conceptualizing the issues. By reading and discussing these studies, our aim was to highlight in a more qualitative way the major methodological approaches, assess their success and limitations, and suggest ways in which current and future work can develop holistic measures that function in an interdisciplinary context to address both the social and ecological dimensions of urban green space.

Finally, "well-being" as a term has been interpreted in different ways. For example, Bell et al. (2007) have limited "health and well-being" literature to the health domain, whereas in the Millennium Ecosystem Assessment (2003) model "well-being" refers to a much wider range of human benefits, including cultural values, to which ecosystem services contribute. Thus, except in relation to our search strategy, outlined above, when we refer to "health and well-being" in this paper, we include literature related to health and well-being, social and community health and well-being, and perceptions and preferences under that description.

Results

Research Mapping

The results of the research mapping exercise are set out in Table 3, which suggests some clear associations between the green space and human health and well-being measures, with each green space measure mapping predominantly onto one or two closely-related human domains.

Studies without any green space measures ("none," n=34) tended to map with human measures of "attitudes, meanings, and values." Within this grouping, the emphasis was on understanding attitudes toward a range of issues, both in relation to specific sites and to more generic conceptualizations of green space and nature. For example, Byrne et al. (2006) examined the spiritual traditions that Australian immigrant groups have toward nature in the context of the Georges River park site in southwest Sydney, Australia; Bright et al. (2002) assessed urban dwellers' beliefs, attitudes, and awareness toward the idea of urban ecological restoration in Chicago, USA; and Herzog et al. (2002) looked at how activities in nature were rated by students in relation to other quotidian and leisure activities.

The "urban versus natural" measures (n=20) were used mainly in studies of the "psychological benefits" derived from exposure to environmental settings. Across this sample of studies, the dichotomy was operationalized in a variety of ways, including comparing the benefits of running in urban or rural settings (Bodin and Hartig 2003); or indoors on a treadmill and outside in natural surroundings (Kerr et al. 2005); of being in rooms with tree views or no views (Hartig et al.

Table 3 ■ Research map of green space by human health and well-being measures, full study set (N=182)

Measures	*Preference*	*Attitudes, meanings, and values*	*Psychological benefits*	*Physical health*	*Behavior*	*Mixed*	*Other*	*Total*
None	1	23	3	1	3	3	0	34
Urban versus natural	1	2	15	0	1	1	0	20
Inventory	1	0	3	0	3	2	0	9
Descriptive/narrative	0	12	3	0	3	2	1	21
Area/distance	0	2	1	11	4	1	3	22
Biophysical	14	4	2	0	2	0	2	24
Human perceptual	8	6	4	2	1	2	0	23
Biodiversity	10	14	1	0	0	1	3	29
All measures	35	63	32	14	17	12	9	182

2003); and exposure to urban as opposed to natural settings depicted in videos (Laumann et al. 2003), or slides (Staats et al. 2003).

"Inventory" measures were used in the least number of studies (n=9) and were spread across human measures of "psychological benefits" and "behavior" and in studies with "mixed" measures. They consisted of a somewhat eclectic list of items, many of which did not relate to green space at all. For example, Sugiyama and Ward Thompson (2008) used a 26-item neighborhood open space scale (which included "trees and plants are attractive") to identify neighborhood attributes that predicted the level of walking in people above the age of 65.

We used the "descriptive/narrative" green space measure (n=21) to categorize qualitative studies where the green space measures or themes were derived from the research participants rather than imposed by the investigators. Most studies using this type of green space measure mapped with studies of "attitudes, meanings, and values." The studies covered a wide range of research topics and consequently there was very little consistency in the themes reported.

"Area/distance" (n=22) was used as a green space measure mainly in studies examining people's "physical health" and "behavior," where in this context behavior referred to physical activity, especially walking. In this cluster of studies, green space was measured either in terms of its proximity to the residence of a research participant (e.g., Cochrane et al. 2009; Takano et al. 2002), or its quantity in terms of area or amount of green space within a given radius from one's residence (e.g., De Vries et al. 2003; Maas et al. 2006; Maas et al. 2009) or within an administrative district that included residences (Mitchell and Popham 2008). In some studies, measures of area and distance were combined (e.g., Neuvonen et al. 2007).

"Biophysical measures" (n=24) mapped predominantly to studies of human "preference" and, to a lesser extent, "attitudes, meanings, and values." For studies coded in this green space category, the focus was on assessing preferences for or acceptability of specific approaches and practices of landscape planning and management. Biophysical measures included the percentage of open land in the view and size of landscape "rooms" in a study of landscape scale (Tveit 2009), the spatial arrangement of trees in brownfield rehabilitation scenarios (Lafortezza et al. 2008), and the specification of different options for managing urban forests (Tyrväinen et al. 2003).

As in the case of "biophysical measures," "human perceptual" measures of green space (n=23) mapped mainly to studies of "preference" and "attitudes, meanings, and values." As cultural constructs of physical green space characteristics, human perceptual measures were not objectively measured or systematically manipulated in the research design, and for our sample of studies were either predefined by the investigator (in the case of “preference” studies), or identified by the investigator or the participant (in studies of “attitudes, meanings, and values”). These measures thus ranged from participant-defined and context-specific to more abstract and generalized. For example, Tyrväinen et al. (2007) mapped residents’ perceptions of the qualities of their local woodlands (e.g. tranquility, the feeling of being in a forest, and naturalness), and Simonič (2003) asked participants to rate photographs of different landscape types for preference and naturalness. The more generalized investigator-defined measures included dimensions based on Kaplan and Kaplan’s (1989) preference matrix (Herzog 1989; 1992), Mozingo’s (1997) principles for the aesthetics of ecological design (Brzuszek and Clark 2007), and the presence of human influence (Van den Berg and Vlek 1998) and signs of care in the landscape (Kaplan 2007).

Finally, “biodiversity” green space measures (n=29) also mapped mainly to studies of “preference” and “attitudes, meanings, and values.” Biodiversity included measures of actual plant and animal diversity (Asakawa et al. 2004; Lindemann-Matthies and Bose 2007; Nassauer 2004a), as well as surrogate measures used in remote sensing, such as NPP (Net Primary Productivity) as an indicator of species diversity and biological productivity (Alessa et al. 2008), and the NDVI (Normalized Differential Vegetation Index) as an indicator of the percentage of vegetated area per setting (Hur et al. 2009). Other proxies for biodiversity included structural complexity, evaluated at a site level by Home et al. (2010) to study preferences for green spaces around social housing; and landscape heterogeneity, mapped by Dramstad et al. (2001) at a landscape scale using remote sensing to study aesthetic appreciation/experience and cultural heritage values. Another approach was to contrast preferences or attitudes toward various scenarios for the enhancement of biodiversity in different contexts, such as the design of residential subdivisions in the United States (Nassauer 2004b) or business sites in the Netherlands (Snep et al. 2009). A further approach was to assess the impact of levels of structural alteration in naturally-occurring vegetation communities on viewer preference (Purcell and Lamb 1998) and judgments of naturalness (Lamb and Purcell 1990).

As applied to our sample of the literature, the research mapping exercise provided a characterization of how urban green space has been conceptualized and measured to address issues of human health and well-being. While our narrative focused on the dominant conceptual combinations in our sample, the matrix in Table 3 also shows areas where there has been less research activity. These gaps, according to Bell et al. (2007), can suggest priorities for future research. There has, for example, been virtually no research into the impact of biodiversity in green spaces on psychological benefits, including psychological restoration, physical health, or behavior, with the notable exception of Fuller et al. (2007).

Innovative approaches to measuring the ecology of urban green space

Out of our sample we selected for in-depth analysis a shortlist of 30 studies that we felt used innovative approaches to address the ecological aspects of urban green space in the context of human health and well-being or highlighted some of the key issues in using green space measures in inter-disciplinary research. As Table 4 demonstrates, these papers were dominated by "biodiversity" (n=18) measures of urban green space, but also included measures from the "biophysical" (n=7), "human perceptual" (n=4), and "descriptive/narrative" (n=1) domains. In terms of the human measures, they mapped mainly onto "preference" and "attitudes, meanings, and values." The following discussion focuses on how green space characteristics are measured and how alternatives for green space design and management are represented to people for evaluation.

Direct and proxy approaches to measuring green space characteristics

In terms of the way biodiversity is measured in our shortlisted sample of papers, a rough distinction can be made between approaches that seek to measure biodiversity on-site and those deploying landscape metric proxies for biodiversity. Examples of the former approach include de la Maza et al. (2002), in which 6 different measures of biodiversity were used to study the association between biodiversity and the income level of residents in the 36 metropolitan boroughs of Santiago, Chile; Kinzig et al. (2005), in which plant and bird diversity were mapped against the income levels of residents of Phoenix, Arizona, U.S.A.; and Fuller et al. (2007), in which urban parks along a transect in Sheffield, U.K. were sampled, *inter alia*, for plant and bird species richness to explore the links between biodiversity and the psychological benefits experienced by park users.

Table 4 ■ Research map of green space by human health and well-being measures, subset of innovative studies (N=30)

Measure	*Preference*	*Attitudes, meanings, and values*	*Psychological benefits*	*Other*	*Totals*
Descriptive/ Narrative		Head and Muir (2006) **(1)**			1
Biophysical	Bjerke et al. (2006); Hands and Brown (2002); Lafortezza et al. (2008); Tyrväinen et al. (2003); Van den Berg and Koole (2006). **(5)**	Breuste (2004) **(1)**		Li and Weng (2007) **(1)**	7
Human perceptual	Kaplan (2007) **(1)**	De Groot and Van den Born (2003); Özguner and Kendle (2006) **(2)**	Korpela et al. (2008) **(1)**		4
Biodiversity	Dramstad et al. (2001); Lindemann-Matthies and Bose (2007); Lindemann-Matthies et al. (2010); Nassauer (2004a); Nassauer (2004b); Ode et al. (2009); Palmer (2004); Purcell and Lamb (1998); Soliva and Hunziker (2009). **(9)**	Bonnes et al. (2007); Hur et al. (2009); Gyllin and Grahn (2005); Lamb and Purcell (1990); Lee et al. (2008); Junker and Buchecker (2008). **(6)**	Fuller et al. (2007) **(1)**	De la Maza et al. (2002); Kinzig et al. (2005). **(2)**	18
Totals	15	10	2	3	30

The main advantages of site-based biodiversity measures seem to be accuracy and site specificity. However, there is no single readily-identifiable measure of biodiversity. In human dimensions research, there is an additional question as to which indicator or combination of indicators has a measurable impact on humans. This may be a question of scale: if the measures are too fine (e.g. where the organisms under investigation are too small, too specialized, or the sampling too localized) or too coarse (e.g. where the spatial unit of measurement is too big), they may be outside the scale of human comprehension (Bonnes et al. 2007). Nassauer (2004a) found that wetland visitors' reports of the frequency with which they saw wildlife were highly correlated with expert-based plant and bird species richness values. Fuller et al. (2007) concluded that green space users were able to perceive species richness of well-known higher taxa, but also hypothesized that users detect biodiversity indirectly: "gross structural habitat heterogeneity might cue the perceptions and benefits of biodiversity" (p. 393). There is considerable support for this more broadly based "structural heterogeneity" hypothesis, including Australian studies which have found that viewers (students and storekeepers) were able to discriminate between different naturally-occurring structural vegetation types and different forms of structural alteration within those types (Lamb and Purcell 1990; Purcell and Lamb, 1998).

Perhaps one of the greatest drawbacks of a site sampling approach to biodiversity measurement in social science research is its resource intensiveness. Fuller et al.'s (2007) protocol for measuring herbaceous plant species richness involved sampling 15 green spaces using 20 quadrats per habitat type up to a maximum of 7 habitat types—a hypothetical maximum of 2,100 quadrats. Woody plant species were sampled using a similar protocol, adding to the sampling load. Another limitation is that if landscape change is to be monitored, the whole sampling procedure has to be repeated.

In contrast to on-site measures of biodiversity, our shortlist also included a number of proxy approaches to biodiversity using remote sensing and GIS. Some of these approaches have already been mentioned in our findings on the full sample of studies (Alessa et al. 2008; Hur et al. 2009). Other remote sensing approaches have used structural heterogeneity or equivalent measures as key variables, lending additional support to Fuller et al.'s (2007) structural heterogeneity hypothesis. Lee et al. (2008) used the normalized difference vegetation index (NDVI) method applied to IKONOS multispectral images to measure the impact of fragmentation, distance, permeability, variability, and connectivity of tree patches on neighborhood satisfaction. In an ambitious multidisciplinary study, Dramstad et al. (2001) used mapped landscape heterogeneity ("the spatial variation of a landscape," p. 260) as a proxy for biodiversity in assessing aesthetic and cultural heritage values in the landscape.

While proxy approaches have obvious pragmatic advantages in terms of being able to use remote sensing data that is often readily available and regularly updated, the Dramstad et al. (2001) study also highlights two problems in using such approaches in interdisciplinary landscape research. The first is that of moving from a two-dimensional, map-based world view to a ground-level representation that relates to the normal human experience of landscape. While landscape heterogeneity and cultural heritage values may be mapped in two dimensions in the GIS, human aesthetic landscape values derive from being able to experience, or at least see, that landscape at a specific location. The second problem is that while GIS can store and display complex information about large-scale, spatially-related resources, human perception tends to operate at a much smaller scale and is constrained by factors not ordinarily recognized in the GIS, such as visual barriers or structures affecting physical movement. In the previously-mentioned study by Lee et al. (2008), the authors state that not enough is known about the critical scales at which humans experience their residential environment, and the same critique can be extended to virtually any environment.

Dramstad et al. (2001) attempted to address these problems by asking a small sample of students to evaluate the aesthetic value of typical ground-level images of the landscapes included in the GIS analysis. But the content of such images is clearly crucial, and sampling must be done systematically, or images must be digitally manipulated, to ensure that the landscape is thoroughly and consistently represented. The latter approach was taken by Ode et al. (2009), who used computer-generated visualizations of a hypothetical landscape containing pasture and broadleaved woodland to explore the relationships between viewer preference and three landscape-level indicators of naturalness (level of succession, number of woodland patches, and shape index of edges). Preference was strongly related to the level of succession and number of woodland patches, and more weakly with the shape index of edges. This work seems to address some of the difficulties in translating mapped landscape indicators into visually comprehensible representations that people can respond to. Presumably if we can use remote sensing data and GIS to extract the critical metrics of landscapes, we can construct a virtual landscape based on those metrics.

Scenario, on-site, and semantic approaches to representing green spaces

The work of Ode et al. (2009) also exemplifies what may broadly be termed the scenario manipulation approach, used frequently in our shortlisted papers. These scenarios used visual images to present green space planning, design, and management alternatives to study participants for evaluation (usually expressed in preference ratings). The scenarios ranged from highly structured alternatives like Ode et al., where green space images were digitally manipulated in a systematic way along one or more variables, to less structured approaches that presented people a range of real-world examples illustrating alternatives without systematic measurement or control of extraneous variables. Hands and Brown (2002) also used digitally altered images to assess employees' reactions to different ecological rehabilitation scenarios of their workplace in Niagara Falls, Canada, demonstrating how visual images and biodiversity or biophysical measures can be used in a focused way to systematically study practical interventions at a site level.

Examples of a less structured, photo-based approach include studies by Kaplan (2007), who used 24 photographs to represent a rough gradient of landscapes with differing natural/urban content and different levels of management in a study of preference and attitudes toward quotidian landscapes around the workplace in Ann Arbor, Michigan, USA; and Tyrväinen et al. (2003), who used a set of 24 photographs to represent different urban forest management options, demonstrating how the scenario manipulation approach may be used in participatory planning in Helsinki, Finland.

Junker and Buchecker (2008) used a structured approach to compare expert ratings of ecological quality and public evaluation of visual attractiveness in the context of river restoration. The authors comment on the "lack of suitable reference scales for varying states of ecological integrity" (p. 142). In this case they used the concept of "eco-morphological quality" (essentially the structural state of river reaches), an approach to river restoration based on the pre-existing "module-step concept" (BUWAL 1998) as the basis for constructing a series of digitally manipulated photographs depicting a river in an artificial, semi-artificial, semi-natural, and near-natural condition. The study is noteworthy for a number of reasons. For one, scenarios based on this approach can be visualized more easily than if they were based on a more abstract concept of biodiversity. Also, the different levels of restoration are established according to objective and replicable criteria and relate directly to real-life scenarios in which the "module-step concept" is to be used. This study also lends weight to Fuller et al.'s (2007) hypothesis that biodiversity is detected by the lay public by means of structural or morphological cues in the landscape.

Junker and Buchecker's (2008) study highlights some of the difficulties inherent in representing spatially explicit ecological models as two-dimensional visualizations, and two of the studies in our sample developed interesting solutions to this problem. Lafortezza et al. (2008) created digital simulations of four landscape rehabilitation scenarios involving soil remediation, the addition of ground cover species, and trees in different spatial configurations. They also used a "Cost Surface Modeling" (CSM) approach, which assigns a "friction value" to each land cover type representing the permeability of the landscape to forest passerines (songbirds). The different rehabilitation scenarios were assigned friction values, as were the rest of the land cover types in the area, and thus the CSM was able to demonstrate how the different remediation options would function at the landscape scale. This innovative approach, however, was compromised by the use of very simplistic visual simulations, and thus while study results showed that the scenarios most favorable to bird dispersal were also more visually preferable, research participants might have reacted less positively to more lifelike remediation scenarios.

Another innovative approach is that of Nassauer (2004b), who used digitally manipulated scenes to evaluate preferences for development scenarios of the urban-agricultural fringe. The ecological implications of three different development scenarios (conventional and ecologically beneficial residential development, and existing agriculture) were evaluated by measuring stream health (presence of suspended materials, chemical composition, and invertebrate species richness) at existing sites having land covers equivalent to those envisaged in the development scenarios. The strengths of this research design lie in its ability to bridge the spatial, temporal, and conceptual boundaries of landscape planning and design: by linking current measures of ecological health to future development scenarios, the study was able to anticipate the ecological impacts that people's development preferences could have across a landscape.

Some of the scenario manipulation approaches in our sample also examined cultural and demographic differences in preference as a function of vegetation density and biodiversity. Bjerke et al. (2006)

measured Norwegian urban residents' recreational preferences for urban park landscapes using photographs varying in vegetation density, and examined preference variations as a function of demographic and environmental value orientations. Soliva and Hunziker (2009) asked Swiss residents to rate visualizations of potential landscape developments under four different scenarios representing a variety of biodiversity management and reforestation options, and to answer a number of text items dealing with biodiversity concepts and values. Van den Berg and Koole (2006) adopted a similar approach in relation to Dutch nature development plans. The advantage of these research designs is that they give additional insights into the cultural and demographic foundations of landscape preferences, which helps to build a picture of how such preferences map onto different sectors of the population and how preferences are likely to change in response to social and biophysical landscape changes.

While the majority of shortlisted studies relied on the development of structured and unstructured photographic scenarios to represent green space ideas and management alternatives for public evaluation, a few studies employed on-site visits and/or semantic approaches of representation. Three of our selected studies used actual sites and, interestingly, each was concerned with eliciting popular meanings of biodiversity, nature, or naturalness. Özguner and Kendle (2006) used a questionnaire to explore the attitudes and values of park visitors toward "nature" and "naturalness" in two urban parks in Sheffield, UK: one naturalistic and one formal. Gyllin and Grahn (2005) used semantic measures to assess attitudes to biodiversity in six different areas characterized by varying management intensity, representing a stratified selection of park types common in southern Sweden. And Head and Muir (2006) used a qualitative, ethnographic approach to study gardeners and their gardens in metropolitan Sydney, Australia, to reveal how notions of boundary making and nativeness expressed through gardening practices helped to define nature perceptions and inform ideas about the management of urban and rural landscapes.

The final example in our shortlisted set of studies by De Groot and Van den Born (2003) relied entirely on textual description. In the study, a mail survey was used to elicit views about the types of nature that people distinguish and the levels of naturalness ascribed to these types of nature; the images that people hold of the appropriate relationship between people and nature and the level of adherence to these images; and people's preference of broadly defined landscape types. This study fills a gap between landscape preference studies and people's views of nature. While at first glance the textual measures used seem somewhat abstract, like the study by Head and Muir (2006), this open-ended approach can help assess the complex cultural "visions of nature" that underpin green space preferences. Their abstraction allowed participants to introduce their own content into the descriptions. This technique may have wider applications in terms of situating people's green space preferences and values within a broader cultural context.

Discussion

In this paper we have attempted to examine recent research on urban green space in the context of human health and well-being. In the context of urban ecological restoration, our analysis shows that while a range of relatively sophisticated measures are being used to assess the biophysical, human perceptual, and biodiversity characteristics of urban green space, most of this work has been focused on a relatively narrow range of human health and well-being dimensions, particularly in the areas of preference and attitudes, meanings, and, values. In contrast, most work on psychological and physical benefits, and behavior (especially studies of physical activity) have relied on relatively simple green space measures such as natural versus urban or area/distance. Our map of the research (Table 3) confirms other recent analyses of the green space literature by Nasar (2008), Van den Berg et al. (2007), and Velarde et al. (2007).

According to Bell et al. (2007), these gaps suggest priorities for future research, and while we generally believe this to be a productive strategy, some green space measures applicable to issues in urban ecological restoration may not readily transfer across all domains of human health and well-being. For example, De Vries et al. (2003) examined the relationship between human health, urbanity, and the amount of green space within one and three kilometers of people's homes. While some broad distinctions were made between different types of green space (urban green, agricultural green, and forests and nature areas), only agricultural green was significant for all the health indicators used in the study. The authors surmise that this is not because agricultural green is inherently better, but because it exceeded other forms of green in the study. In other words, it is the amount of green space that may be crucial and not its particular characteristics, and even then the authors question whether the amount of green may just be another way of measuring the natural versus urban dimension. Thus, it should not be assumed that all green space measures are salient across the entire spectrum of human benefits.

A more productive strategy for future research into these benefit domains thus should seek to establish which types of green space promote particular well-being outcomes, and how interactions with different types of green space may be mediated by cultural and demographic factors. Indeed, much of what may loosely be termed landscape research is concerned with the need for integration between research disciplines, and between research and practice across the fields of landscape planning, design, and management (Borgström et al. 2006; Morton et al. 2009). Interdisciplinary collaboration between the social and natural sciences involves the consideration of multiple parameters and multiple scales across the dimensions of time, spatiality, and process (Tress et al. 2003), and it therefore is unlikely that a single environmental measure would ever be capable of working effectively across the full range of these disciplines. Thus the development of more complex models is called for, and a number of authors, including Fry et al. (2009) and Tzoulas et al. (2007) have made significant progress in this direction.

Several of the shortlisted studies that we reviewed in-depth (Table 4) suggest that structural landscape heterogeneity may be one of the most promising green space measures, with the potential to integrate different disciplinary perspectives and scales. The evidence suggests that structural heterogeneity may be the principle means by which humans detect biodiversity in the landscapes around them (Fuller et al. 2007) in that it can be used to integrate the assessment of different landscape values at a landscape scale using a GIS (Dramstad et al. 2001) and be systematically represented in digital simulations to gauge public reaction to particular planning, design, or management outcomes (Junker and Buchecker 2008; Nassauer 2004b; Ode et al. 2009). The creation or retrofitting of green infrastructure as the basis for future sustainable urban development involves the establishment of multifunctional green networks, and it seems likely that structural landscape heterogeneity could become one of the principal means by which their effectiveness is measured against multiple parameters. However, many of the studies that used a form of structural landscape heterogeneity as an environmental measure were conducted in a rural context, and it may prove to be less effective in urban areas, where parcels of green space are smaller, more fragmented, and vegetation communities are more disturbed (Purcell and Lamb 1998).

To be truly effective, such models need to accommodate a paradigm shift that sees humans not merely as "an exogenous perturbing force, but as an interactive species on the landscape, structuring their surroundings to achieve a particular suite of environmental amenities" (Kinzig et al. 2005: 2). As these authors point out, this involves recognizing that the social, political, economic, administrative, and cultural processes that have hitherto been considered separately from the ecology of the natural landscape are in fact deeply implicated in its development and change.

As a final note, both the studies included in the research mapping exercise and the final shortlist were predominantly quantitative in their methodological approach, and many relied on what we have called the scenario manipulation approach, using mainly visual stimuli. This bias toward quantitative and visual studies was the outcome of our emphasis on explicit green space measures, which are often absent from qualitative research. In focusing on the former we accept that we have excluded from consideration some important aspects of human health and well-being and methodological approaches that rely on hands-on, multi-sensory experiential interaction with green space (e.g., Gobster 2008).

Conclusion

Urban ecological restoration provides a set of ecologically-based concepts and practices that challenge managers to think of urban green space as more than "simply green." By creating more structurally complex environments in a wider range of urban green spaces, managers can address a number of issues that are at the forefront of urban ecology, including sustainability, biodiversity, and the provision of ecosystem services (Ingram 2008; Nowak and Dwyer 2007). But there is also an important human side to urban ecological restoration, and as seen in this review of the recent literature, studies of green space and human health and well-being are using a diverse range of ways to measure the green in green space in ways that are relevant and meaningful to people. Work on human-green space interactions has generally shown a positive relationship between measures of biodiversity and preference, but it also shows important exceptions in different contexts, for different demographic and cultural groups, and for different domains of human health and well-being. Further cross-disciplinary research is needed as those working in urban ecological restoration seek to integrate social concepts and practices with ecological ones.

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Notes

1. While green space is largely characterized by its vegetation, it may also include water features, wildlife, and built facilities that support use or other associated functions.
2. The full list of study citations is available from the authors upon request.

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