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Nature Contact and Human Health: A Research Agenda

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Background: At a time of increasing disconnectedness from nature, scientific interest in the potential health benefits of nature contact has grown. Research in recent decades has yielded substantial evidence, but large gaps remain in our understanding.

Objectives: We propose a research agenda on nature contact and health, identifying principal domains of research and key questions that, if answered, would provide the basis for evidence-based public health interventions.

Discussion: We identify research questions in seven domains: *a*) mechanistic biomedical studies; *b*) exposure science; *c*) epidemiology of health benefits; *d*) diversity and equity considerations; *e*) technological nature; *f*) economic and policy studies; and *g*) implementation science.

Conclusions: Nature contact may offer a range of human health benefits. Although much evidence is already available, much remains unknown. A robust research effort, guided by a focus on key unanswered questions, has the potential to yield high-impact, consequential public health insights. https://doi.org/10.1289/EHP1663

Introduction

Humans are increasingly disconnected from nature. Most people—over half globally, and approximately four in five Americans—live in urban areas, where nature contact is typically limited (United Nations 2015). Surveys reveal that Americans spend >90% of their time indoors: most of that time is spent in buildings, and a smaller portion in vehicles (Klepeis et al. 2001). Screen time has reached daily averages of 1 h 55 min for children younger than 8 y old (Rideout 2013) and 7 h 38 min for those between 8 and 18 y old (Rideout et al. 2010). In 2016, the average "total media consumption" was 10 h 39 min per day among adults and was rising (Nielsen 2016). Park visitation, hunting, fishing, camping, and children's outdoor play have all declined substantially over recent decades (Clements 2004; Frost 2010; Pergams and Zaradic 2008).

In this context, recent years have seen a blossoming of scientific interest in the benefits of nature contact for human health and well-being. Several recent reviews have summarized and evaluated the growing evidence base (Bowler et al. 2010; Hartig et al. 2014; James et al. 2015; Lee and Maheswaran 2011; Martens and Bauer 2013; Russell et al. 2013; Seymour 2016). This literature reveals an extraordinarily broad range of benefits, albeit with varying levels of evidentiary support (Table 1).

Despite this considerable body of evidence, key questions remain unresolved (Frumkin 2013). In this paper, we propose a research agenda on nature contact and health, with the aim of systematically identifying key questions that merit research attention.

Definitions and Scope

A necessary starting point is the definition of nature contact. In general, by "nature" we mean "areas containing elements of living systems that include plants and nonhuman animals across a range of scales and degrees of human management, from a small urban park through to relatively 'pristine wilderness'" (Bratman et al. 2012), together with abiotic elements such as sunset or mountain views. We acknowledge that multiple definitions of nature are appropriate, varying with the form of nature contact being studied and the ways in which people relate to nature. We note the far-reaching discourse on nature as a social construct (Cronon 1996), which is beyond the scope of this paper. Similarly, there is a philosophical argument that humans are a part of nature, a view that calls into question any distinction between humans and nature, and hence the very possibility of "nature deficit" (Fletcher 2016). This argument is beyond the scope of this paper. The important category of animal contact, the subject of a large body of literature (Barker and Wolen 2008; Kamioka et al. 2014; Matchock 2015), is beyond the scope of this paper, as are the health benefits of the food and materials resulting from harvesting activities such as foraging, fishing, and hunting.

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Table 1. Summary of evidence-based health benefits of nature contact.

No.	Health/well-being benefits	References
1	Reduced stress	Berto 2014; Fan et al. 2011; Nielsen and Hansen 2007; Stigsdotter et al. 2010; van den Berg and Custers 2011; van den Berg et al. 2010; Ward Thompson et al. 2016
2	Better sleep	Astell-Burt et al. 2013; Grigsby-Toussaint et al. 2015; Morita et al. 2011
3	Improved mental health:	
	Reduced depression	Astell-Burt et al. 2014c; Beyer et al. 2014; Cohen-Cline et al. 2015; Gascon et al. 2015; Kim et al. 2009; Maas et al. 2009b; McEachan et al. 2016; Nutsford et al. 2013; Sturm and Cohen 2014; Taylor et al. 2015; White et al. 2013
	Reduced anxiety	Beyer et al. 2014; Bratman et al. 2015a; Maas et al. 2009b; Nutsford et al. 2013; Song et al. 2013; Song et al. 2015
4	Greater happiness, well-being, life satisfaction	Ambrey 2016; Fleming et al. 2016; Larson et al. 2016; MacKerron and Mourato 2013; Van Herzele and de Vries 2012; White et al. 2013
5	Reduced aggression	Bogar and Beyer 2016; Branas et al. 2011; Kuo and Sullivan 2001a, b; Troy et al. 2012; Younan et al. 2016
6	Reduced ADHD symptoms	Amoly et al. 2014; Faber Taylor et al. 2001; Faber Taylor and Kuo 2009; Faber Taylor and Kuo 2011; Kuo and Faber Taylor 2004; Markevych et al. 2014b; van den Berg and van den Berg 2011
7	Increased prosocial behavior and social connectedness	Broyles et al. 2011; Dadvand et al. 2016; de Vries et al. 2013; Fan et al. 2011; Holtan et al. 2015; Home et al. 2012; Piff et al. 2015; Sullivan et al. 2004
8	Lower blood pressure	Duncan et al. 2014; Markevych et al. 2014a; Shanahan et al. 2016
9	Improved postoperative recovery	Park and Mattson 2008; Park and Mattson 2009; Ulrich 1984
10	Improved birth outcomes	Reviewed by Dzhambov et al. 2014
11	Improved congestive heart failure	Mao et al. 2017
12	Improved child development (cognitive and motor)	Fjørtoft 2001; Kellert 2005
13	Improved pain control	Acutely (Diette et al. 2003; Lechtzin et al. 2010) and chronically (Han et al. 2016)
14	Reduced obesity	Bell et al. 2008; Cleland et al. 2008; P. Dadvand et al. 2014a; Lachowycz and Jones 2011; Sanders et al. 2015; Stark et al. 2014
15	Reduced diabetes	Astell-Burt et al. 2014a; Bodicoat et al. 2014; Brown et al. 2016; Thiering et al. 2016
16	Better eyesight	French et al. 2013; Guggenheim et al. 2012; He et al. 2015
17	Improved immune function	Li et al. 2006; Li et al. 2008a; Li et al. 2008b; Li et al. 2010; Li and Kawada 2011
18	Improved general health:	
	Adults	Brown et al. 2016; de Vries et al. 2003; Kardan et al. 2015; Maas et al. 2006; Maas et al. 2009b; Stigsdotter et al. 2010; Wheeler et al. 2015
	Cancer survivors	Ray and Jakubec 2014
	Children	Kim et al. 2016
19	Reduced mortality	Coutts et al. 2010; Gascon et al. 2016b; Hu et al. 2008; James et al. 2016; Takano et al. 2002; Villeneuve et al. 2012
20	Asthma and/or allergies (studies show both improvements and exacerbations)	Andrusaityte et al. 2016; Dadvand et al. 2014a; Fuertes et al. 2014; Fuertes et al. 2016; Lovasi et al. 2013; Lovasi et al. 2008; Ruokolainen et al. 2015

Note: ADHD, attention-deficit hyperactivity disorder. The references in Table 1 are illustrative rather than exhaustive; they include both recent reviews and research reports and older, widely cited publications.

There are many forms of nature contact, varying by spatial scale, proximity, the sensory pathway through which nature is experienced (visual, auditory, etc.), the individual's activities and level of awareness while in a natural setting, and other factors. Figure 1 displays various examples of nature contact along just two of these two scales, spatial and temporal. Much contemporary research focuses on greenspace as the exposure of interest, perhaps because of ease of measurement, but we take a broader approach, ranging from plants in a room to views through windows to camping trips to virtual reality imagery. Researchers must define and operationalize the specific form of nature contact they are studying. We return to this point below in our discussion of exposure assessment.

With regard to outcomes, we take a broad definition of health, including physical and mental health, social well-being, academic and job performance, and happiness. The effects of nature contact on proenvironmental knowledge, attitudes, and behavior are the subject of an extensive body of literature (Collado et al. 2015; Wells and Lekies 2006) but are beyond the scope of this paper. Similarly, the outcomes we consider are limited to those affecting humans, excluding impacts of human–nature contact on other species or on natural systems more generally.

Methods

We assembled a multidisciplinary group at the University of Washington including expertise in epidemiology, environmental health, clinical medicine, psychology, ecology, landscape architecture, urban studies, public policy, and anthropology. The group studied published reviews of the nature–health connection, as well as primary research reports, and discussed research needs with end-users ranging from conservationists to nature preschool administrators to parks officials. Through iterative discussion and consensus formation, we sought to identify domains in which important questions remain unanswered, and in which research would advance the field. Within each domain, we identified specific research priorities.

Several principles guided the formulation of this research agenda. First, we recognized the value of diverse disciplines and professions. Second, we recognized the need to balance linear, reductionist approaches to research with complex, systems-based approaches, as advocated in other relevant domains of research (Dooris 2006; Liu et al. 2007), and we entertained research topics and strategies reflecting both approaches. Third, we recognized the need to integrate quantitative and qualitative data, and we entertained research topics that would draw on both kinds of data. Fourth, we emphasized research topics that are relevant and useful for decision makers and affected communities so that research results might have the greatest likelihood of being applied and benefiting people. Fifth, we emphasized research topics that, when appropriate, could engage affected populations both in defining research questions and methods and in conducting the research. For example, community-based participatory research, a well-established set of methods that improve the quality and relevance of research (Blumenthal et al. 2013; Jason and

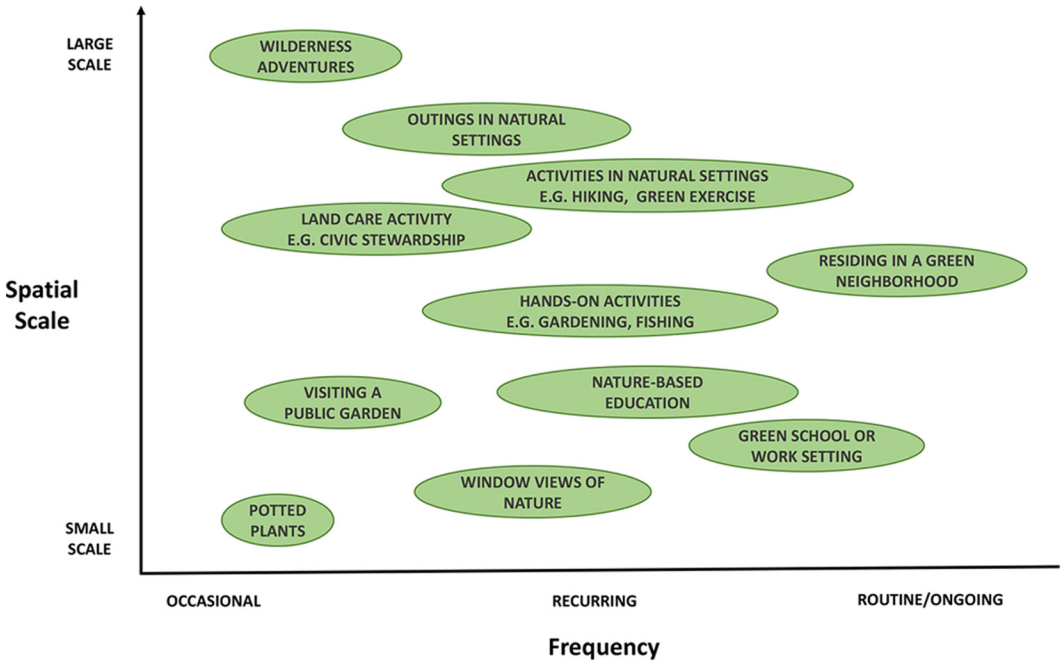

Figure 1. A spectrum of forms of nature contact.

Glenwick 2016), has been applied to the study of nature contact (Bijker and Sijtsma 2017).

We identified seven domains of research on nature contact and health, as shown in Table 2. We considered ranking topics within each domain in order of importance but elected not to do so, mindful that in this highly interdisciplinary and context-dependent field, different investigators and decision makers likely differ in their scientific perspectives and information needs. However, we did identify top-level research questions based on scientific importance, tractability, and potential public health impact; these questions are designated with bold-face type in the listings that follow.

Domain 1: Mechanistic Biomedical Studies

A central aspect of health research is identifying the mechanisms that account for observed health effects: for example, the components of cigarette smoke that are carcinogenic and the immunologic pathways by which the smallpox vaccine confers protection. With respect to nature contact and health, the diversity of benefits suggests a broad, nonspecific physiological pathway of action, a multiplicity of pathways, or a combination of these. These pathways may have an evolutionary origin, as proposed by the biophilia hypothesis (Kellert and Wilson 1993; Wilson 1984). The mechanisms are only partially understood, and authors are unanimous in noting the need for deeper understanding (Dadvand et al. 2016; de Vries et al. 2013; Groenewegen et al. 2012; Hartig et al. 2014; Keniger et al. 2013; Lachowycz and Jones 2013; Shanahan et al. 2015b; Sullivan and Kaplan 2016). Such understanding would be invaluable in designing and testing strategies for delivering beneficial nature contact.

Table 2. Nature contact and health research domains.

Domain
1. Mechanistic biomedical studies
2. Exposure science
3. Epidemiology of health benefits
4. Diversity and equity considerations
5. Technological nature
6. Economic and policy studies
7. Implementation science

Several mechanisms have been hypothesized: psychological pathways, enhanced immune function, physical activity, social contact, and improved air quality. Each of these is considered below.

Psychological Pathways

Two complementary theoretical frameworks, both invoking psychological mechanisms, have been identified (Berto 2014). Stress Recovery Theory (SRT) emphasizes the role of nature in relieving physiological stress, whereas Attention Restoration Theory (ART) emphasizes the role of nature in relieving mental fatigue.

Stress reduction is both a health benefit in and of itself and a potential mechanism for other health benefits (Lovallo 2015). Some research has focused on short-term indicators: for example, experiments that expose subjects to stressful stimuli with and without nature contact and measure acute responses such as skin conductance and salivary cortisol levels (Parsons et al. 1998; Ulrich et al. 1991; van den Berg and Custers 2011). Other research has focused on a longer time frame: for example, comparing people living in more- and less-green neighborhoods with regard to subjective levels of stress (Nielsen and Hansen 2007; Stigsdotter et al. 2010; Ward Thompson et al. 2016) or ability to cope with stressful life events (van den Berg et al. 2010; Ward Thompson et al. 2016). The results consistently show that nature contact reduces stress; the relative importance of this direct pathway, and mediation through social contact, physical activity, and/or other factors, is less clear (Ward Thompson et al. 2016).

Attention restoration was proposed as a mechanism by Kaplan and Kaplan (Kaplan and Kaplan 1989; Kaplan 1995). This theory holds that excessive concentration can lead to "directed attention fatigue," and that contact with nature—specifically with sufficient extent to feel immersed, and in ways that confer a sense of being away, that capture attention effortlessly ("soft fascination"), and that are compatible with personal preferences—engages a less taxing, indirect form of attention, thereby facilitating recovery

of directed attention capacity. Empirical support has come from studies of attention deficit disorder (Faber Taylor and Kuo 2009, 2011; van den Berg and van den Berg 2011) and from diverse settings and populations (Brunson et al. 2001; Evensen et al. 2015; Li and Sullivan 2016). There is some evidence that the two mechanisms—stress reduction and attention restoration—may operate concurrently, yielding cognitive and affective benefits independently or through an interaction of the psychological processes involved (Li and Sullivan 2016).

Additional psychological mechanisms might interact with (or be independent of) stress reduction, attention restoration, or both. What is the role of awe—the sense of wonder, amazement, and smallness that may occur in response to perceptually vast stimuli (Keltner and Haidt 2003; Piff et al. 2015; Rudd et al. 2012; Shiota et al. 2007)? What is the role of mystery—the allure of seeing and knowing more by entering more deeply into a setting (Herzog and Bryce 2007; Szolosi et al. 2014)? How does nature contact influence the regulation of emotions (in adaptive and/or maladaptive ways) (Bratman et al. 2015a)? How might personality structure mediate the benefits of nature contact (Ambrey and Cartlidge 2017)? How might stress reduction and attention restoration operate differently in different groups, based on such factors as cultural background and socioeconomic position (Russell et al. 2013)?

Each of these constructs—stress reduction, attention restoration, awe, mystery—is based in theory. With increasing use of more precise psychophysiological measures in both laboratory and field settings, it is likely that they will evolve toward operationally defined constructs grounded in specific neural pathways.

Enhanced Immune Function

In a recent review, Kuo (Kuo 2015) argued that improved immune function accounts for many of the health benefits of nature, based on meeting three criteria: accounting for the magnitude of observed health benefits; accounting for the specific health outcomes observed; and subsuming other possible pathways. Nature contact may enhance immune function in at least two ways on very different time scales. First, consistent with the "hygiene hypothesis," contact with microbial and other antigens in natural settings during particular developmental windows may modify immune function over the lifespan (Hanski et al. 2012; Kondrashova et al. 2013; Nicolaou et al. 2005; Rook 2013; Ruokolainen et al. 2015; Stiemsma et al. 2015), perhaps operating through effects on the microbiome (Lee and Mazmanian 2010). Second, short-term exposures to some natural substances (such as phytoncides from trees) have been associated with improved natural killer (NK) cell activity (Li et al. 2006, 2008a, 2008b, 2010; Li and Kawada 2011). Stress recovery and immune function mechanisms may not be distinct because of reciprocal relationships between these two physiologic systems (Irwin and Cole 2011; Nusslock and Miller 2016).

Increased Physical Activity

Physical activity confers a broad range of health benefits, including prevention and/or amelioration of obesity, cardiovascular disease, some cancers, diabetes, some mental illness, osteoporosis, gall bladder disease, and other conditions (Bauman et al. 2016; Lee et al. 2012; WHO 2010). Natural surroundings such as vegetated streetscapes, parks, and schoolyards are generally associated with higher levels of physical activity in both children and adults, a plausible mechanism for many of the observed health benefits of nature contact (Bancroft et al. 2015; Bingham et al. 2016; Calogiuri and Chroni 2014; Fraser and Lock 2011; Gray et al. 2015; Hunter et al. 2015; Kaczynski and Henderson 2007; Koohsari et al. 2015; Lee et al. 2015; O'Donoghue et al. 2016; Shanahan et al. 2016; Sugiyama et al. 2014). The mechanisms by which green surroundings might facilitate physical activity are not well understood; aesthetic preference may play a role (Shanahan et al. 2016). In children, evidence suggests that play in natural environments is associated with the development of motor skills such as balance and coordination, which in turn enable and predict physical activity (Fjørtoft 2001; Fjørtoft 2004). The dynamic and irregular characteristics of natural play spaces may explain this observation. Some studies have demonstrated a benefit from green neighborhoods independent of physical activity (Cohen-Cline et al. 2015; Fan et al. 2011; Feda et al. 2015; Nielsen and Hansen 2007), and some studies have found weak or no association between nature contact and physical activity (Gubbels et al. 2016; Hillsdon et al. 2006; Witten et al. 2008), suggesting that physical activity only partially accounts for health benefits. A challenge in interpreting these results is the possibility of reverse causation: people inclined to be physically active may seek recreation in green, outdoor settings. Moreover, the nature → physical activity → health pathway may vary across subpopulations, settings, levels of access, programming, and other factors.

A promising line of research regarding physical activity in natural settings pertains to "green exercise." There is some evidence that physical activity in outdoor, natural settings confers more benefits than equivalent exertion in indoor or constructed settings (Barton et al. 2016; Coon et al. 2011). A better understanding of this phenomenon might help clarify the mechanisms by which nature contact benefits health.

Social Connectedness

Social connectedness is strongly associated with health (Kawachi et al. 2008). To the extent that nature contact promotes social connections, this may be a mechanism for associated health benefits (Maas et al. 2009a).

Support for this pathway comes from studies of prosocial behavior and of social capital (networks of social relationships and the norms of trust and reciprocity). With regard to prosocial behavior and attitudes, observational studies of residential greenness (Dadvand et al. 2016; Kweon et al. 1998; Sullivan et al. 2004) and of nearby parks (Fan et al. 2011) and experimental studies of brief nature exposures (Piff et al. 2015; Zelenski et al. 2015) have found an association between nature contact and prosocial outcomes. [One exception was a study of children in Kaunas, Lithuania, which found the opposite result (Balseviciene et al. 2014)]. With regard to social capital, studies have found that living in greener neighborhoods (de Vries et al. 2013; Holtan et al. 2015; Kemperman and Timmermans 2014) and using parks (Broyles et al. 2011; Home et al. 2012; Kaźmierczak 2013) are associated with greater social cohesion, with the strength and extent of social networks, or with both. Further research could clarify the ways in which natural features promote social connectedness and how this pathway interacts with other possible mechanisms of benefit.

Improved Air Quality

Air quality in rural or wilderness settings is generally superior to that in urban settings. In urban settings, tree canopy may reduce ambient levels of particulate matter and gaseous air pollutants, although most studies find this air-quality improvement to be slight (Nowak et al. 2013; Nowak et al. 2014). Moreover, any benefits must be weighed against potential disbenefits. Trees can in some cases worsen asthma (Andrusaityte et al. 2016; Dadvand et al. 2014a; Kimes et al. 2004; Lovasi et al. 2013), a likely result of pollen, soil fungi, other vegetation-associated allergens, the

production of hydrocarbons (ozone precursors), or a combination of these factors (Grote et al. 2016). Trees can also impede air circulation, reducing the dispersion of air pollutants in urban canyons (Vos et al. 2013). To the extent that vegetation improves air quality, nature contact may offer protection against respiratory and cardiovascular disease.

Other Benefits of Nearby Nature

There are myriad other benefits of nearby nature that extend beyond these psychological and physical health mechanisms (Bolund and Hunhammar 1999; Livesley et al. 2016; Tzoulas et al. 2007). For example, urban vegetation, particularly trees, can reduce and filter storm-water runoff (Berland et al. 2017); regulate local temperatures, resulting in attenuated heat island effects (Bowler et al. 2010) and reduced energy demand (Nowak et al. 2017); provide pollination services (Hall et al. 2017; Threlfall et al. 2015) and wildlife habitat (Alvey 2006; Murgui and Hedblom 2017); reduce urban noise (Margaritis and Kang 2017); and sequester and store carbon (Davies et al. 2011). Larger natural areas outside of cities can contribute even more to carbon sequestration and storage, water filtration, and timber and game production.

Proposed research priorities

1.1. **To what extent does stress reduction mediate observed health benefits of nature contact?**
  1.1a. Both short-term and long-term
  1.1b. Which natural elements are most associated with stress reduction?
  1.1c. Which markers of stress reduction are most useful in studying this effect?

1.2. **To what extent does improved immune function mediate observed health benefits of nature contact?**
  1.2a. Both short-term and long-term
  1.2b. Which natural elements are most associated with improved immune function?
  1.2c. Which markers of immune function are most useful in studying this effect?
  1.2d. What is the role of the human microbiome in mediating this effect?

1.3. **To what extent does social connectedness account for, or mediate, observed health benefits of nature contact?**
  1.3a. Both short-term and long-term
  1.3b. Which social arrangements or activities best optimize the benefits of nature contact through this pathway?

1.4. **Does nature-based physical activity confer benefits above and beyond equivalent physical activity in nature-free settings?**
  1.4a. If so, which natural elements best account for the additional benefits?

1.5. **For each of these potential mechanisms, how do other factors—demographic, social, biomedical, and ecological—affect the associations between nature contact and health?**

Domain 2: Exposure Science

Exposure science (or exposure assessment) is: "the process of estimating or measuring the magnitude, frequency, and duration of exposure to an agent, along with the number and characteristics of the population exposed. Ideally, it describes the sources, pathways, routes, and the uncertainties in the assessment" (Zartarian et al. 2005). This discipline is a *sine qua non* of research on environmental impacts on people, whether the research focus is on pathogens, medications, toxic chemicals, social circumstances, or salutary exposures such as nature (Armstrong et al. 2008; Lioy and Weisel 2014; Nieuwenhuijsen 2003). Despite the centrality of exposure assessment in epidemiologic research, there is little agreement on how best to define nature contact for research purposes (Hunter and Luck 2015; Taylor and Hochuli 2017), let alone how to measure it (Mitchell et al. 2011; Wheeler et al. 2015). Various approaches have been used.

In some research, **quantitative measures** of natural elements serve as metrics of nature contact. Most recent research has measured greenspace; as noted above, greenspace is a more limited construct than nature contact. Two main kinds of exposure metrics are typically used: "cumulative opportunity" and distance (Ekkel and de Vries 2017). Cumulative opportunity refers to the total amount of nearby greenness (on the assumption that nature contact is proportional to this parameter). The most frequently used measure is the Normalized Difference Vegetation Index (NDVI), which assesses the density of photosynthetically active biomass based on satellite imagery (Gascon et al. 2016a; Rhew et al. 2011). Related metrics include the Enhanced Vegetation Index (EVI) (Huete et al. 2002), the Leaf Area Index (LAI) (Hu et al. 2014), the Building Proximity to Green Spaces Index (BGPI) (Li et al. 2014), and Object-Based Image Analysis (OBIA) using light detection and ranging (LiDAR), a laser-based imaging technology (MacFaden et al. 2012). To date, most studies have defined exposure to these quantitative measures based on the residential environment, an approach limited by spatial resolution and subject to misclassification (if people spend highly variable amounts of time at home). However, such data can be combined with Global Positioning System (GPS) tracking using devices such as smartphones to characterize individual exposure patterns as people move about during defined periods of observation (Chaix et al. 2013). The second quantitative approach, distance to greenspace, such as distance from home to a park, uses geospatial information. Few studies have compared cumulative opportunity and distance as exposure assessment strategies, but in studies that used both (Amoly et al. 2014; Coutts et al. 2010; Dadvand et al. 2014b; Jonker et al. 2014; Triguero-Mas et al. 2015), cumulative opportunity was a better predictor of health outcomes (Ekkel and de Vries 2017) [with at least one exception (Grazuleviciene et al. 2015)].

Semiquantitative measures of nature contact are also used. Examples include the presence or absence of plants in a classroom (Han 2009), the presence or absence of a tree view from a window (Ulrich 1984), the proportion of aquatic elements in a picture (White et al. 2010), or the density of fish in an aquarium (Cracknell et al. 2016). At a larger spatial scale, land-use or land-cover maps are often used. These maps classify landscape elements as "dense urban," "forest," "cropland," and so on. An extensive listing of such databases is available for the United States at the U.S. Geological Survey Land Cover Institute web site (https://landcover.usgs.gov/) and for the United Kingdom at the U.K. Office for National Statistics Generalised Land Use Database (https://data.gov.uk/dataset/land_use_statistics_generalised_land_use_database). "Exposure" is approximated by integrating the time spent in each setting. Innovative technology permits more complex characterizations. For example, Google Street View can be used to assess the degree of nature encountered by a person at street level (Li et al. 2016). Similarly, social media data can help quantify visits to natural areas and behavior patterns within those areas (Sessions et al. 2016; Wood et al. 2013).

Standard approaches to exposure measurement share at least five limitations. First, they fail to capture variations in how people experience nature, nuances that may be highly relevant to

health benefits (Kahn 2010). Suppose that one person sits in a car atop a seaside bluff and admires the view of the beach (while checking e-mail on a smartphone), a second person walks barefoot along the shore, enjoying not only the view but the feel of the sea breeze and the lapping waves, and a third person plunges in for a swim. The designation "beach contact" or a measure of "time at the beach" would fall far short of capturing the variation in their experiences. Among the relevant variables are the specific sensory modalities involved. Most research assumes that people's contact with nature is visual, but other modes, such as auditory (Conniff and Craig 2016; Feld 2015), tactile, and olfactory, likely play a role. Specific forms of nature contact (Step 4 in Figure 2) need to be identified and measured.

Second, commonly used exposure measures have low reproducibility. Several studies have assessed the concordance among various measures of greenspace or tree canopy. These measures include direct observation; the use of Google Street View, Google Earth, or similar technologies; and the use of secondary sources such as land-cover data sets (Ben-Joseph et al. 2013; Charreire et al. 2014; Clarke et al. 2010; Pliakas et al. 2017; Rundle et al. 2011; Taylor et al. 2011). These measures have generally shown poor to fair agreement among the different approaches, suggesting a pervasive problem with measuring greenspace exposure (much less nature contact).

Third, commonly used exposure measures cannot quantify the "dose," that is to say, what a person experiences during an episode of nature contact. If two people—one observant and highly attuned to nature, the other oblivious or distracted—both walk down the same forest path, they are likely to "absorb" differing levels of nature. "Nature connectedness" and/or awareness may be important (and highly culture-specific) mediators of "dose," and through it of health benefits (Cervinka et al. 2012; Lin et al. 2014; Perrin and Benassi 2009). Even among people who are highly attuned to nature, perceptions may vary substantially (Beaudreau et al. 2011; Stier et al. 2017). **Qualitative measures** may have a role in addressing such limitations. Indeed, subjective ratings of vegetation or scenery (Hoyle et al. 2017; Seresinhe et al. 2015) may approximate "dose" as well as, or better than, objective measures. Emerging technologies such as smartphone apps that allow people to describe their surroundings may play an important role here (Schootman et al. 2016). Such crowdsourced data need to be evaluated in terms of validity and generalizability.

Fourth, standard exposure measures typically focus more on physical than on temporal attributes. As in pharmacology and toxicology, the duration and frequency of exposure are important components of dose. If two people live in the same neighborhood with a certain amount of tree canopy, but one has lived there for 20 y and takes a 30-min walk each day, whereas the other just moved there a year ago and only ventures outside twice a month for 10 min each time, the two people have substantially different exposure profiles, a difference not captured by measures of their neighborhood street canopy.

Fifth, standard exposure measures are not grounded in the ecological elements most relevant to human health and well-being. What is it about a walk in the forest that confers benefits? Is it the vegetation type (Wheeler et al. 2015)? The level of biodiversity (Dallimer et al. 2012; Lovell et al. 2014; Rook 2013)? Does it matter if the trees are in leaf, or is a wintertime walk equally effective? Is wildness required, or does an orderly tree farm or agricultural field suffice? Precisely which elements of exposure need to be measured?

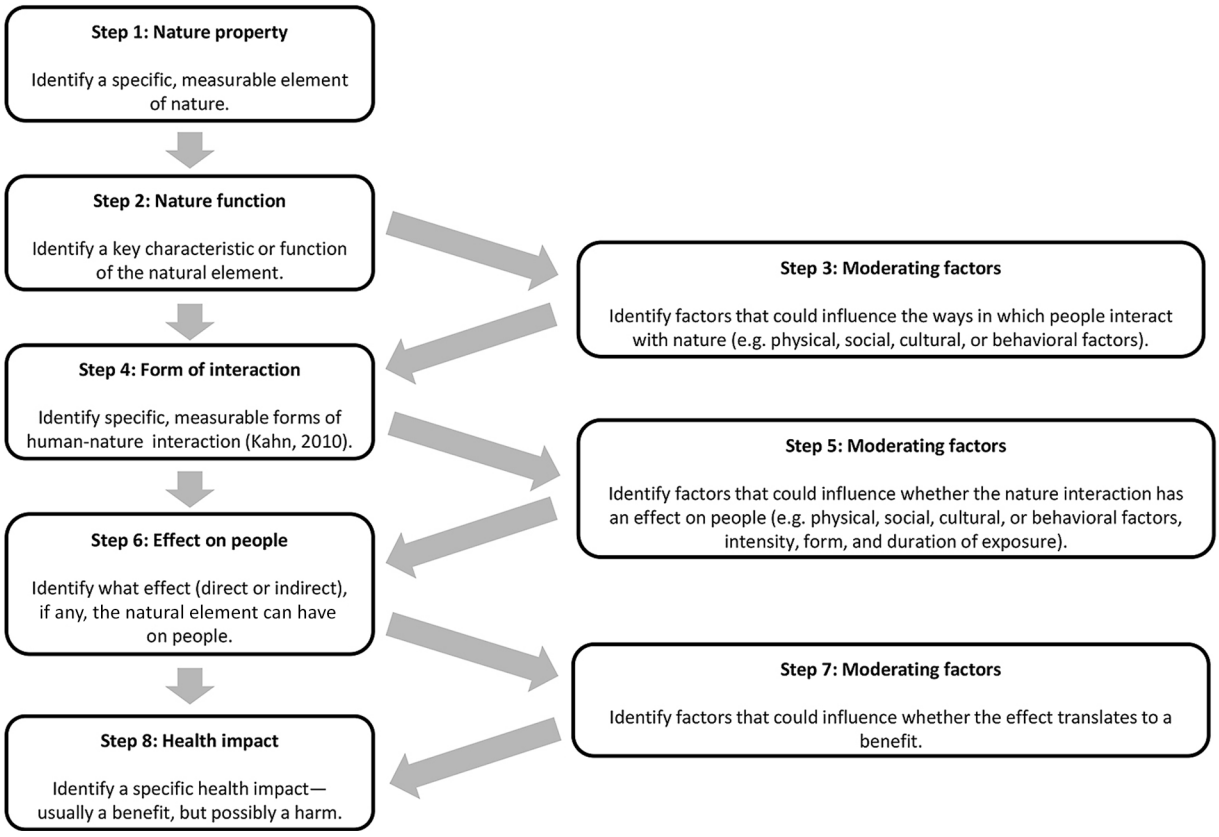

Figure 2. A proposed framework for studying the health benefits of nature contact (adapted from Shanahan et al. 2015b).

The choice of exposure metrics is consequential; there is evidence that research findings may vary with the exposure metrics used. For example, a study of green space exposure in relation to general health (Akpinar et al. 2016) found that "aggregated green space" performed differently from "forest," and that urban green space performed differently from rural green space, in predicting mental health complaints.

Research is needed across all metrics of nature exposure to identify the metrics that are most accurate and precise and that best predict human responses of interest. The resulting insights, coupled with better knowledge of mechanisms of benefit, are needed to guide the provision of "the best dose of the best exposures."

Proposed research priorities

2.1. **Which metrics of nature best predict various health benefits?**
2.2. **For each such metric, what is its accuracy? What is its precision?**
2.3. What is the role of subjective assessments, and of "nature connectedness," in measuring nature contact?
2.4. How do exposure metrics vary in their performance by population and other factors?
2.5. What are the roles of duration and frequency of exposure in predicting health benefits?

Domain 3: Epidemiology of Health Benefits

The State of Research

Although recent research has identified many associations between nature contact and health, much remains to be learned. The body of epidemiologic research consists principally of three categories of study: true experiments, "natural experiments," and observational studies, with observational studies accounting for the preponderance of the literature.

True experiments are the gold standard in science. In the nature and health domain, examples include clinical trials of nature imagery for pain relief during medical procedures (Diette et al. 2003; Lechtzin et al. 2010), of nature adventure therapy in the treatment of post-traumatic stress disorder (PTSD) in veterans (Gelkopf et al. 2013), of horticultural therapy in pain management (Verra et al. 2012), and of park walks in workplace stress management (de Bloom et al. 2017). The challenges of such experiments include their cost and the difficulty of assessing long-term outcomes; indeed, most reported trials have been limited to relatively short-term outcomes. Opportunities include the emergence of innovative techniques for measuring outcomes that can be readily applied in experimental settings (see below).

Natural experiments are study opportunities that resemble experiments but that arise through circumstances outside the investigator's control (Dunning 2012). In the nature and health domain, examples include a comparison of surgical outcomes in patients with and without views of trees through their hospital room windows (Ulrich 1984); a comparison of women's health in counties with and without tree loss resulting from emerald ash borer infestation (Donovan et al. 2015); a comparison of self-discipline in children living in public housing with and without nearby trees (Taylor et al. 2002); and a study of crime and stress in relation to the greening of neglected vacant lots, comparing blocks already treated with blocks not yet treated (Branas et al. 2011). In each instance, the strength of the study depends on the extent to which the two groups compared do not differ in ways other than the exposure of interest. Natural experiments have important advantages: they are opportunities to study realistic exposures in realistic settings, they can study long-term outcomes more readily than true experiments, and they can be far less expensive than true experiments. They can yield powerful insights, as illustrated by John Snow's classic study of water sources during the 1854 cholera epidemic in London (Snow 1855). However, natural experiments pose several challenges for researchers. Practically, they require a nimble and rapid response once a study opportunity is recognized, often exceeding the capacity of funders, ethics committees, and other institutional structures. The more thorny challenge is conceptual: natural experiments are highly susceptible to bias, that is to say, to the tendency for exposure to vary across a study population by factors that are also associated with outcomes (Craig et al. 2012; Rutter 2007). Confounding and reverse causation can be difficult to exclude. For example, if people who walk in natural settings evince lower levels of stress than those who do not, is that because the nature contact has a salutary effect, or is it because people who are better at managing their stress choose to take more nature walks?

Finally, retrospective observational studies comprise the bulk of the literature on nature contact and health. Examples include the many recent studies of various health outcomes according to the greenness of residential neighborhoods. These studies have several advantages. They are practical. They can be conducted more rapidly than prospective studies. They can readily address long-term health outcomes. By using data collected for other purposes, they reduce costs. However, they also face the considerable challenges of controlling bias and confounding as well as the potential limits of data not designed specifically for testing nature–health hypotheses.

Directions for Future Research

Potential enhancements in epidemiologic research on the nature–health connection include innovative data sources, more diverse study settings, improved exposure assessment (discussed above), innovative outcome measures, and improved analytical approaches.

With respect to data sources, one option is tapping into large, ongoing cohort studies. For example, a recent analysis of the Nurses' Health Study (NHS) examined the association between residential greenness and causes of death (James et al. 2016). This analysis benefited from the well-established, high-quality exposure and outcome data in an ongoing study. A related option is adding measures of nature contact to ongoing studies. For instance, both the Behavioral Risk Factor Surveillance System (BRFSS) and the National Health Interview Survey (NHIS) inquire about physical activity, but until now, neither has inquired about whether that activity takes place outdoors.

Improved computing capabilities offer the possibility of acquiring and analyzing "big data" from innovative sources. Examples include administrative data from health care systems (Birkhead et al. 2015; Mazzali and Duca 2015), mobile health data (Chen et al. 2012; Hayden 2016), environmental sources such as Google Street View and webcams (Schootman et al. 2016), and social media sources such as Twitter (Hamad et al. 2016). For instance, with smartphone apps such as Mappiness (http://www.mappiness.org.uk/), Track Your Happiness (https://www.trackyourhappiness.org/), and Urban Mind (https://www.urbanmind.info/), users record their emotions. These responses are geolocated, permitting the study of minute-to-minute associations between proximity to nature and emotional states. The same is true for disease-specific apps such as Share the Journey, developed to study breast cancer (http://sharethejourneyapp.org/).

With regard to study settings, most studies of nature contact and health have been carried out in cool, temperate climates,

generally in high-income countries. Relatively little research has evaluated desert, mountainous, or shoreline landscapes—places where major population centers are located. Similarly, little research has been based in low- and middle-income settings, with their distinct profiles of environmental conditions and health vulnerabilities. Epidemiologic research in such settings will extend knowledge considerably.

Innovative outcome measures offer great promise when applied to health research on nature exposure (Haluza et al. 2014). These measures include stress indicators such as cortisol, amylase, and skin conductance (Beil and Hanes 2013; Jiang et al. 2014; JJ Roe et al. 2013); measures of brain activity including novel EEG methods (Aspinall et al. 2015; J Roe et al. 2013; Tilley et al. 2017) and functional brain imaging (Bratman et al. 2015b); genetic markers such as leukocyte basal gene expression profiles (Fredrickson et al. 2013); and telomere shortening (Woo et al. 2009). The use of physiological measurements may help elucidate mechanisms of action, as discussed above.

Finally, because nature contact invariably operates as part of a complex web of health determinants, statistical analysis must address this complexity. Analytical techniques including multilevel analysis (Diez-Roux 2000), complex causal process diagrams (Joffe and Mindell 2006), path analysis and structural equations, and the use of counterfactuals (Berzuini et al. 2012; Pearl 2009; Pearl et al. 2016) may all be useful in controlling bias and confounding; in disentangling multivariate, multilevel, bidirectional associations; and in clarifying causal pathways.

Advancing epidemiologic research requires both the improved methods described above as well as confirmation and clarification of specific associations. Figure 2 (based on Shanahan et al. 2015b) shows a model for this research. In this figure, a natural element such as tree canopy is identified and associated with defined functions (such as casting a shadow) that have direct or indirect effects on people (such as reducing UV radiation exposure) that in turn affect health (such as reducing skin cancer risk). The association between ecosystem functions and human effects may be subject to mediation and effect modification by a range of factors; these are encompassed by the term "moderating factors" in Figure 2.

Of the innumerable potential associations between nature contact and health, which are the most important to study? Although priorities will vary from setting to setting, the most common exposures (for example, urban greenspace, given the preponderance of people who live in cities) and the most common and/or high-consequence outcomes (such as conditions that account for a high burden of suffering) should be research priorities. Research should also focus on characterizing associations in ways that are relevant to practice, such as by defining dose–response relationships. Additionally, as discussed below, research should focus on subpopulations at particular risk or on those that could benefit disproportionately from nature contact, such as children, the elderly, and deprived groups.

Proposed research priorities

3.1. **How is nature contact associated with specific health outcomes of public health importance, such as cardiovascular disease, cancer, depression, anxiety, well-being, and happiness?**
   3.a. How do these associations vary across different populations, life stages, and other factors?
   3.b. Which forms of nature contact are most beneficial?

3.2. **What "dose" and duration of exposure are needed to yield a benefit?** How long does the beneficial effect last? Can habituation occur, with attenuated benefit over time?

3.3. If people born and raised in one setting relocate to a setting with different natural features, do the benefits of nature contact still operate?

3.4. Are there particular benefits from contact with landscapes or ecosystems that align with human evolutionary origins and/or with conservation priorities?

3.5. What are the adverse effects, if any, of nature contact?

Domain 4: Diversity and Equity—The Role of Nature Contact

At least four major strands of research are needed with respect to diversity and equity: *a*) patterns of disproportionate exposure; *b*) cultural and contextual factors that affect nature preferences and the experience of nature; *c*) differing patterns of benefit across different populations; and *d*) the possibility that improved access to nature may have unintended negative consequences on vulnerable populations.

With respect to disparities in access to nature, there is considerable evidence that disadvantaged urban populations are relatively deprived of access to nature and greenspace (Astell-Burt et al. 2014b; Boone et al. 2009; Dahmann et al. 2010; Heynen et al. 2006; Jennings and Gaither 2015; Jennings et al. 2016; Li et al. 2016; Pedlowski et al. 2002; Schwarz et al. 2015; Wolch et al. 2014). Much of this research centers on park access in urban settings. In some circumstances, studies have shown disadvantaged populations to have equal or greater proximity to parks and tree canopy (Barbosa et al. 2007; Cutts et al. 2009; Rigolon 2016; Schwarz et al. 2015; Vaughan et al. 2013; Wen et al. 2013), but typically in these situations, the quality of the parks, the level of programming, and/or park access remain significant barriers to park use.

There is also evidence that nature preferences vary across ethnic, cultural, and racial backgrounds. Tragically, the legacy of forced labor, lynchings, and other violence may evoke deeply disturbing associations with trees, fields, and forests among some African Americans (Johnson et al. 1997; Johnson and Bowker 2004). Diverse populations also express diverse preferences with respect to greenspace: a baseball diamond for some, a soccer field for others, picnic facilities for still others (Gobster 2002; Ho et al. 2005; Payne et al. 2002; Smiley et al. 2016). Similarly, the preferred forms of nature contact may vary: a group activity for some, solitary hikes for others. Such differences are deeply rooted in historical and geographic context (Buijs et al. 2009; Byrne and Wolch 2009). Livelihood may play an important role: a rural farmer likely has quite different preferences regarding nature from those of an urban computer programmer. These cultural and other filters may help determine whether, and how, nature contact confers health benefits. (There are limits to this approach: people may not fully recognize and report their own preferences, and attention restoration or other mechanisms could operate independently of preference or even awareness.) Research is needed to clarify the origin and durability of such preferences and their effects on health benefits. In practical terms, research on how best to engage communities in planning parks and greenspace will likely yield the best-performing facilities in terms of park use, health, and well-being.

There is evidence that contact with nature and greenspace may disproportionately benefit disadvantaged populations, attenuating the toxic effects of poverty and reducing health disparities—the so-called "equigenic" effect (Lachowycz and Jones 2014; Maas et al. 2006; Mitchell and Popham 2007, 2008; Mitchell et al. 2015). This effect needs to be confirmed and clarified in different settings, using a variety of study designs. If nature contact can help mitigate the toxic effects of poverty, this information could help guide interventions both to achieve both social justice goals

and to realize the greatest return on investment in terms of human well-being.

Finally, improvements in access to greenspace may lead to "green gentrification," an increase in property values that displaces low-income residents from their neighborhoods (Anguelovski 2017; Lewis and Gould 2017; Miller 2016; Wolch et al. 2014). This process needs to be studied and understood so that its adverse effects can be prevented.

Research on these dimensions of equity with respect to nature contact will permit both understanding the interplay of social disadvantage and nature contact and designing and targeting the most effective strategies for improving health and well-being for all (Rutt and Gulsrud 2016; Smiley et al. 2016).

Potential research priorities

4.1. **How does access to nature vary by socioeconomic status, ethnicity, cultural background, and other social factors, in specific settings?**
4.2. **How do preferences and perceptions of nature vary by socioeconomic status, ethnicity, and other demographic factors, in specific settings, and how do these differences affect choices regarding time in nature?**
4.3. What are the obstacles, both subjective and objective, to increasing the frequency of nature contact for disadvantaged communities?
4.4. **How do the benefits of nature contact vary by socioeconomic status, ethnicity, and other demographic factors, in specific settings?**
4.5. What unintended negative consequences flow from "green gentrification," and what policies and practices help avoid those consequences?

Domain 5: Technological Nature

Modern information and communication technology that leverages digital computation is becoming exponentially more sophisticated and pervasive and may profoundly alter the human relationship with nature (Kahn 2011; Kurzweil 2005). Increasing use of technology—as exemplified by growing "screen time," particularly among children—can compete with such activities as play in natural settings (Radesky and Christakis 2016; Vanderloo 2014) enough to have prompted the American Academy of Pediatrics to recommend limits on children's screen time (Council on Communications and Media 2016).

However, technology does not only interfere with nature contact. "Technological nature" refers to technologies that mediate, simulate, promote, and/or augment the human experience of nature (Kahn 2011). Examples include real-time digital screen representations of local nature (digital nature "windows"), robot pets, and tele-robot-operated gardens. Virtual reality applications may simulate nature-based experiences (Guttentag 2010; Schutte et al. 2017), and the Pokémon Go game, during a peak in popularity in 2016, may have triggered outdoor activity (although the quality of the resulting nature interaction is unknown) (Althoff et al. 2016; Dorward et al. 2017; Howe et al. 2016). Other smartphone apps may facilitate or inform a connection with nature; examples include apps that assist with identifying trees, birds, or constellations.

Studies of people interacting with technological nature have begun to suggest that such interaction is better for people than no exposure to nature, but not as beneficial as genuine nature exposure (Kahn Jr et al. 2008; Kahn 2011; Melson et al. 2009). However, whether this initial trend generalizes across a wide range of human metrics, and if so, whether it will persist with increasing fidelity of technological nature, remain open questions. Research could also focus on the ways in which technological nature could broaden and even change the human experience of nature. One near-future example is linking apps with networked artificial intelligence conversational systems. Virtual reality is also a near-future pervasive form of interaction in social media and beyond, including in contact with the natural world (Guttentag 2010). Because of the growing role of technology in human–nature interactions, it is important to understand how best to harness technology to maximize health benefits.

Technological nature may be useful in another way: laboratory-based controlled experiments utilizing technology may help tease apart which aspects of the nature experience have which effects on people and how these effects are moderated according to individual differences. Here again, attention would need to be paid to how the technological nature experience compares to the actual nature experience.

Proposed research priorities

5.1. **How can specific forms of technological nature increase and deepen the human experience of nature?**
5.2. Where, how, and why does technological nature fall short in conferring human benefits relative to the actual experience of nature?
5.3. **What forms of technological nature contact provide health benefits, and what are those benefits?**
5.4. How do these findings vary by technology, context, and across age groups and other demographic factors?
5.5. What insights can virtual nature contact provide into the causal mechanisms of psychological benefits, and how ecologically valid will these insights be?

Domain 6: Economic and Policy Studies, Including Cobenefits

The benefits of nature contact need to be studied and tested not only as scientific hypotheses but also as policy propositions; this requires quantitative estimates of the value of these benefits. The principal intellectual framework for this approach comes from the field of ecological economics (Costanza 2015; Farley and Daly 2011; Stagl and Common 2005), and more particularly from the analysis and valuation of ecosystem services (Hester and Harrison 2010; Ninan and Costanza 2014; Ruckelshaus et al. 2015). Both civil society (Harnik and Welle 2009; NRPA 2015) and academic researchers (Naidoo et al. 2006; Roy et al. 2012; Shoup 2010) characterize the ecosystem services provided by parks and greenspace, tree canopy, open land, and other natural assets. However, these analyses generally focus on biophysical processes such as storm water management, air quality, and erosion control, omitting explicit consideration of human health and well-being. Key reports often fail even to mention human health, much less to quantify it as an ecosystem service (Fisher et al. 2009; Posner et al. 2016; Seppelt et al. 2011)—an omission that is likely to lead to incorrect conclusions and suboptimal policies.

Fortunately, recent publications have begun to integrate human health into ecosystem services analyses (Bayles et al. 2016; Breslow et al. 2016; Ford et al. 2015; Lindgren and Elmqvist 2017; Salmond et al. 2016; Sandifer et al. 2015; Willis and Petrokofsky 2017) and even to propose quantitative metrics (Jackson et al. 2013; Smith et al. 2013). In some cases, research identifies and quantifies the health cobenefits of green infrastructure and/or conservation efforts, providing a more complete picture than would otherwise be available (Coutts and Hahn 2015; Larsen et al. 2012; Wolf and Robbins 2015). Health economics research can help value both health gains and relatively intangible benefits such as aesthetic enjoyment and happiness, as well as

help quantify avoided health care costs, attributable to nature contact. Although precise estimates may be elusive and uncertainty must be acknowledged, in many cases, health benefits will be large enough to rival other ecosystem services in value. Importantly, this work needs to take a life course approach; although average medical costs during childhood are low, investments in nature contact early in life may yield substantial health improvements, and avoided medical costs, later in life (Wolf et al. 2015). Moreover, analysis needs to account for disbenefits of nature contact, such as allergic reactions and excessive sunlight exposure. Much more research and analysis are needed to address these issues.

Cost–benefit analyses need to estimate how much benefit will flow from specific kinds of investments in nature contact and to make comparisons among policy alternatives, a key consideration for city officials, park managers, and other decision makers confronting the reality of limited resources (Ruckelshaus et al. 2015). This research requires mechanistic models that can predict a mix of monetary and nonmonetary ecosystem services. Teams of scientists and policy makers need to be highly multidisciplinary to perform "full benefit accounting" that considers both health benefits and nonhealth benefits (ranging from storm water management to biodiversity protection to enhanced property value) of nature's services.

As noted above, policy research needs to include a strong focus on equity issues—from documenting disparities in nature access to testing solutions to preventing gentrification and other unintended consequences of interventions.

Proposed research priorities

6.1. What are the best methods for valuing the health benefits of nature?

6.2. **What is the health-related value of various forms of nature contact?**
- 6.2a. Cost–benefit analyses
- 6.2b. Cost-effectiveness analyses
- 6.2c. Long-term analyses across the life span
- 6.2d. Integration with other ecosystem services assessments

6.3. **What are the optimal methods of combining both health and nonhealth cobenefits of various forms of nature contact?**

Domain 7: Implementation Science—Studies of What Works

Research findings do not necessarily translate into action. According to one leading researcher, "[d]issemination and implementation of research findings into practice are necessary to achieve a return on investment in our research enterprise and to apply research findings to improve outcomes in the broader community" (Colditz 2012). This is the motivation for implementation science—research that "supports movement of evidence-based effective health care and prevention strategies or programs from the clinical or public health knowledge base into routine use" (Colditz 2012). Although descriptive studies can identify and quantify health benefits of nature contact, intervention studies are needed to determine what works in practice (Kondo et al. 2015).

Like translational research in medicine, designed to bring research findings "from the bench to the bedside" to improve patient outcomes, studies of the nature–health association can be designed with real-world application in mind. Such studies might be structured as true experiments, consistent with clinical trials used routinely in biomedical research. They might also take the form of program evaluations following a wide range of interventions. Integrated quantitative and qualitative research may provide the most comprehensive understanding of health impacts, from individual to community scales. Important products of such work are predictive models and decision tools for use by planners and decision makers. For example, some cities use tools such as the U.S. Forest Service's i-Tree software (http://www.itreetools.org/) to analyze environmental services associated with tree planting. Might further development of such tools incorporate additional mental and physical health benefits?

Proposed research priorities

(Examples only; research topics in this domain will vary by particular circumstances)

7.1. With respect to specific interventions designed to promote health and well-being through nature contact, how are they implemented (legal and administrative arrangements, partnerships, costs, and financial mechanisms), and how do they work (in terms of attracting people and yielding desired outcomes)? Examples of potential high-impact research include the following:
- 7.1a. Which trail and park designs perform best in promoting physical activity (Qviström 2016)?
- 7.1b. How should children's play spaces be designed to optimize nature contact (Gundersen et al. 2016)?
- 7.1c. Which configurations of children's outdoor schools optimize health, social relationships, and learning (Roe and Aspinall 2011; Söderström et al. 2013)?
- 7.1d. Which design features in natural settings (such as sweeping views, known as "prospect," and safe places to hide, known as "refuge") make them most restorative (Gatersleben and Andrews 2013)?
- 7.1e. What dose of nature is needed to optimize benefits (Hunter and Askarinejad 2015; Shanahan et al. 2015a, 2016)? How is that dose most effectively delivered? Are programs such as Park Prescriptions, in which health care providers direct their patients to spend time in natural settings, effective (Coffey and Gauderer 2016)?
- 7.1f. Which outdoor programs most effectively treat post-traumatic stress disorder in veterans (Poulsen et al. 2015)?
- 7.1g. What is the efficacy of horticultural therapy in treating dementia, anxiety, stress, and other conditions in the institutionalized and noninstitutionalized elderly (Detweiler et al. 2012)?

Conclusions

According to the best available evidence, nature contact offers considerable promise in addressing a range of health challenges, including many, such as obesity, cardiovascular disease, depression, and anxiety, that are public health priorities. Nature contact offers promise both as prevention and as treatment across the life course. Potential advantages include low costs relative to conventional medical interventions, safety, practicality, not requiring dispensing by highly trained professionals, and multiple cobenefits. Few medications can boast these attributes.

However, many questions regarding the health benefits of nature contact remain unanswered. A robust program of scientific research is needed to generate evidence-based answers to these questions. This paper has identified seven domains of research that, together, frame an agenda for needed research: mechanistic biomedical studies, exposure science, epidemiologic studies, studies focusing on diversity and equity, studies of technological nature, economic and policy studies, and implementation science.

Although particular challenges exist in such areas as exposure assessment, innovative data sources and analytical techniques represent exciting opportunities. The results of such research will guide interventions across a wide range of settings, populations, spatial scales, and forms of nature. Health professionals, ecologists, landscape architects, parks staff, educators, and many others will in turn be able to apply these results to improve health and well-being on a large scale.

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