

## SOCIAL SCIENCES

# Nature and mental health: An ecosystem service perspective

Gregory N. Bratman<sup>1,2,3,4\*</sup>, Christopher B. Anderson<sup>3,5</sup>, Marc G. Berman<sup>6,7</sup>, Bobby Cochran<sup>8</sup>, Sjerp de Vries<sup>9</sup>, Jon Flanders<sup>10,11</sup>, Carl Folke<sup>12,13,14</sup>, Howard Frumkin<sup>15,16</sup>, James J. Gross<sup>17</sup>, Terry Hartig<sup>18,19</sup>, Peter H. Kahn Jr.<sup>1,20</sup>, Ming Kuo<sup>21</sup>, Joshua J. Lawler<sup>1,2</sup>, Phillip S. Levin<sup>1,2,22</sup>, Therese Lindahl<sup>14</sup>, Andreas Meyer-Lindenberg<sup>23</sup>, Richard Mitchell<sup>24</sup>, Zhiyun Ouyang<sup>25</sup>, Jenny Roe<sup>26</sup>, Lynn Scarlett<sup>27</sup>, Jeffrey R. Smith<sup>3,5</sup>, Matilda van den Bosch<sup>28,29</sup>, Benedict W. Wheeler<sup>30</sup>, Mathew P. White<sup>30</sup>, Hua Zheng<sup>25</sup>, Gretchen C. Daily<sup>3,4,5,31\*</sup>

Copyright © 2019  
The Authors, some  
rights reserved;  
exclusive licensee  
American Association  
for the Advancement  
of Science. No claim to  
original U.S. Government  
Works. Distributed  
under a Creative  
Commons Attribution  
NonCommercial  
License 4.0 (CC BY-NC).

A growing body of empirical evidence is revealing the value of nature experience for mental health. With rapid urbanization and declines in human contact with nature globally, crucial decisions must be made about how to preserve and enhance opportunities for nature experience. Here, we first provide points of consensus across the natural, social, and health sciences on the impacts of nature experience on cognitive functioning, emotional well-being, and other dimensions of mental health. We then show how ecosystem service assessments can be expanded to include mental health, and provide a heuristic, conceptual model for doing so.

## INTRODUCTION

Human well-being is linked to the natural environment in myriad ways, and actionable understanding of these links is deepening in diverse disciplines (1–3). Many of the contributions of living nature (diversity of organisms, ecosystems, and their processes) to people's quality of life can be referred to as “ecosystem services.” They include water purification, provision of food, stabilization of climate, protection from flooding, and many others (2). Worldwide, major efforts are underway to bring ecosystem services and their values into policy, finance, and management (4–6).

These efforts rely increasingly upon models that relate scenarios of change in ecosystems to change in the provision of services (7), and they have been adopted on an international scale. For example, the Natural Capital Project's InVEST models (for Integrated Valuation of Ecosystem Services and Tradeoffs) are being used in 185 countries around the world (6). The InVEST models are based on production functions that define how changes in an ecosystem's composition, configuration, and function are likely to affect the flows and values of ecosystem services across a landscape or seascape. They are open source and are being tested and adapted through a broad network. In some areas, such as in hydrology, this modeling is advanced and builds upon decades of work, although challenging frontiers remain (8). In other areas, such as pollination services for agriculture and human nutrition (9), the modeling and its empirical basis are in comparatively early stages of development. These models are designed to be used in an ensemble to estimate change in multiple ecosystem services.

To date, these modeling and decision-making efforts have focused predominantly on services tied to biophysical dimensions of Earth's life-support systems and more recently on cultural services (10). However, relatively little attention has been given in the field of ecosystem services to the ways in which nature experience directly affects human mental health (see Box 1 for our definitions of “nature” and “nature experience”), with a few important exceptions (11). This omission is particularly concerning in light of indications that mental illness accounts for a substantial proportion of suffering in all regions of the world (12). The fraction of the total global burden of disease (GBD) attributable to mental illness has recently been estimated to be as high as 32% of total years lived with disability (YLD) (13) and 13% of disability-adjusted life-years (DALYs), on par with cardiovascular and circulatory diseases (13). It is important, therefore, to determine the degree to which nature experience might lessen this burden—and to integrate these effects into ecosystem service assessments.

## NATURE EXPERIENCE AS A DETERMINANT OF MENTAL HEALTH

A variety of interacting factors can affect mental health, including social, economic, psychological, physiological, behavioral, environmental,

<sup>1</sup>School of Environmental and Forest Sciences, University of Washington, Seattle, WA 98195, USA. <sup>2</sup>Center for Creative Conservation, University of Washington, Seattle, WA 98195, USA. <sup>3</sup>Center for Conservation Biology, Stanford University, Stanford, CA 94305, USA. <sup>4</sup>The Natural Capital Project, Stanford, CA 94305, USA. <sup>5</sup>Department of Biology, Stanford University, Stanford, CA 94305, USA. <sup>6</sup>Department of Psychology, University of Chicago, Chicago, IL 60637, USA. <sup>7</sup>Grossman Institute for Neuroscience, Quantitative Biology, and Human Behavior, University of Chicago, Chicago, IL 60637, USA. <sup>8</sup>Willamette Partnership, Portland, OR 97239, USA. <sup>9</sup>Wageningen Environmental Research, Wageningen University and Research, Wageningen, Netherlands. <sup>10</sup>School of Biological Sciences, University of Bristol, Bristol, UK. <sup>11</sup>Bat Conservation International, Austin, TX 78746, USA. <sup>12</sup>Global Economic Dynamics and the Biosphere, Royal Swedish Academy of Sciences, Stockholm, Sweden. <sup>13</sup>Stockholm Resilience Centre, Stockholm University, Stockholm, Sweden. <sup>14</sup>Beijer Institute, Royal Swedish Academy of Sciences, Stockholm, Sweden. <sup>15</sup>Wellcome Trust, London, UK. <sup>16</sup>School of Public Health, University of Washington, Seattle, WA 98195, USA. <sup>17</sup>Department of Psychology, Stanford University, Stanford, CA 94305, USA. <sup>18</sup>Institute for Housing and Urban Research, Uppsala University, Uppsala, Sweden. <sup>19</sup>Department of Psychology, Uppsala University, Uppsala, Sweden. <sup>20</sup>Department of Psychology, University of Washington, Seattle, WA 98195, USA. <sup>21</sup>Landscape and Human Health Laboratory, Department of Natural Resources and Environmental Sciences, University of Illinois, Urbana, IL 61801, USA. <sup>22</sup>The Nature Conservancy, Seattle, WA 98121, USA. <sup>23</sup>Central Institute of Mental Health, Medical Faculty Mannheim/University of Heidelberg, Mannheim, Germany. <sup>24</sup>Centre for Research on Environment, Society and Health, Institute of Health and Wellbeing, University of Glasgow, Glasgow, UK. <sup>25</sup>State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing, China. <sup>26</sup>Center for Design and Health, University of Virginia, Charlottesville, VA 22904, USA. <sup>27</sup>The Nature Conservancy, Fairfax, VA 22203, USA. <sup>28</sup>School of Population and Public Health, University of British Columbia, Vancouver, British Columbia, Canada. <sup>29</sup>Department of Forest and Conservation Sciences, University of British Columbia, Vancouver, British Columbia, Canada. <sup>30</sup>College of Medicine and Health, University of Exeter Medical School, Exeter, UK. <sup>31</sup>Stanford Woods Institute, Stanford University, Stanford, CA 94305, USA.

\*Corresponding author. Email: bratman@uw.edu (G.N.B.); gdaily@stanford.edu (G.C.D.)

**Box 1. Definitions.**

**Mental health.** Mental health is defined by the World Health Organization as “a state of well-being in which [an] individual realizes his or her own potential, can cope with the normal stresses of life, can work productively and fruitfully, and is able to make a contribution to her or his community” (101). Conceived in this way, mental health encompasses (i) the absence of mental illness and (ii) the presence of psychological well-being.

**Mental illness** entails the occurrence of disorders of cognition, affect, and behavior, typically defined through *The Diagnostic and Statistical Manual of Mental Disorders* (102) or the *International Classification of Diseases* (103). These include highly prevalent conditions such as depression, anxiety, dementia, and substance use disorders, as well as less common but often severe illnesses such as schizophrenia, autism, and bipolar disorder.

**Psychological well-being** comprises multiple affective and cognitive components, including happiness—both hedonic (enjoyment and pleasure) and eudaimonic (purpose, meaning, and fulfillment)—self-actualization (accomplishments, optimism, and wisdom), resilience (capacity to cope, adaptive emotion regulation, and lack of maladaptive problem-solving), and healthy relationships (104). For the purpose of this framework, we also include aspects of cognitive functioning (e.g., attention and working memory) and a lack of mental distress (e.g., stress and loneliness).

**Nature** encompasses elements and phenomena of Earth’s lands, waters, and biodiversity, across spatial scales and degrees of human influence, from a potted plant or a small urban creek or park to expansive, “pristine” wilderness with its dynamics of fire, weather, geology, and other forces (105).

**Nature experience** includes individuals’ perceptions and/or interactions with stimuli from the natural world (from potted plants and private gardens to more expansive public green space and wilderness, weather, and the movements of the sun) through a variety of sensory modalities (sight, hearing, taste, touch, and smell) (22). These experiences can occur through conditions of “real” (in situ) contact, window views, representations (e.g., landscape photographs), or simulations (e.g., virtual reality). They may be deliberate or incidental, will ordinarily be colored by personal associations and sociocultural meanings, and can occur in the context of diverse activities (e.g., park visits and passive viewing). Within this broad range of types of experiences, our primary focus in this paper is on the benefits received from interactions with nature in situ, as this is most relevant to the ecosystem service framework.

genetic, and epigenetic influences (14). It is important to note that, in many cases, these social and environmental determinants of health may outweigh the effects of nature contact on specific outcomes. Contextual factors determining global levels of mental illness and health include, but are not limited to (see the Supplementary Materials for references), marked demographic shifts in the world’s population (such as aging), social shifts involving increased stress and loneliness, physical shifts to more sedentary lifestyles, and the factor upon which we focus here—certain aspects of urbanization and a loss of many avenues for experiencing nature on a regular basis for some people (15).

Several aspects of contemporary lifestyles are associated with reduced routine nature contact. One is urban living (15). Cities are centers of prosperity, employment opportunities, access to education, health and human services, and cultural advancement, all aspects of life that may promote mental health (16). However, they can also be associated with decreased access to nature, especially for individuals living within economically deprived urban areas (17). Other factors

contributing to a decrease in nature contact include perceived barriers (such as fear) (18), increased time spent indoors and on screens, and decreased outdoor recreation activities (see the Supplementary Materials for references). In recent decades, investigators in public health and health economics have intensified empirical research on the role of nature contact and the environment as a general health promoter, including mental health (11, 19–22). Excluded from our considerations here are the clear ways in which nature contact may be harmful to health, such as wildfires, wildlife attacks, and allergies.

**PUTTING SCIENCE INTO PRACTICE**

There is a clear demand from practitioners and decision makers to incorporate the emerging evidence regarding the mental health effects of nature experience into ecosystem service assessments and policy. Here, we frame the positive mental health values of engaging with nature as “psychological ecosystem services.” We begin with an overview of the evidence base, culminating in statements of consensus reflecting our collective knowledge. From this foundation, we then propose a conceptual model for the mental health effects derived from nature experience.

**THE BODY OF EVIDENCE**

Research has shown that various types of nature experience are associated with mental health benefits in many ways (23–28). For instance, controlled laboratory studies have demonstrated beneficial psychological and stress/physiological impacts of nature images and sounds (29). Experimental fieldwork has also shown the benefits of nature experience by contrasting within-group change across affective, cognitive, and physiological dimensions in participants who walked in natural versus urban environments (30–32). Cross-sectional and longitudinal research has found that the psychological well-being of a population can be associated, in part, with its proximity to green space, blue space (i.e., aquatic and marine environments), and street trees or private gardens in both urban (33–37) and rural settings (38). Some cross-sectional studies suffer from the presence of confounders (e.g., neighborhood-level socioeconomic characteristics), while other experimental and longitudinal work addresses and illuminates causal mechanisms (21).

Although many of these findings are correlational, the confluence of results from experimental and correlational studies is encouraging. In particular, there is now a mounting body of evidence from experimental studies that nature exposure plays a causal role in improving affect in the short term. What is currently less well established is whether these affective changes play a causal role in influencing longer-term mental health.

Mental health benefits may vary by socioeconomic status, preferences, residential location, occupation, personality traits, culture, gender, and age (39). Effects may also differ according to the type of interaction with nature (described below) (40), and the form of sensory input (e.g., visual, olfactory, auditory, or tactile). In addition, little is known about the duration of these effects, although some studies have found that some benefits last for substantial periods of time (see the Supplementary Materials for references). This is an important aspect to consider when framing nature exposure as a benefit to long-term mental health. It also bears noting that much of this work is situated in urban contexts within the Global North

(41). Diversification to other locales and sociocultural perspectives would greatly extend understanding.

### **CONSENSUS STATEMENT #1: EVIDENCE SUPPORTS AN ASSOCIATION BETWEEN COMMON TYPES OF NATURE EXPERIENCE AND INCREASED PSYCHOLOGICAL WELL-BEING**

A wealth of studies has demonstrated that nature experience is associated with psychological well-being. These include investigations of single as well as cumulative occasions of nature contact, and range from experimental to observational designs. The forms of association include evidence that links nature experience with increased positive affect (26, 30, 32); happiness and subjective well-being (42); positive social interactions, cohesion, and engagement (43, 44); a sense of meaning and purpose in life (45); improved manageability of life tasks (46); and decreases in mental distress, such as negative affect (32, 47). In addition, with longitudinal studies, as well as natural and controlled experiments, nature experience has been shown to positively affect various aspects of cognitive function (48), memory and attention (30, 32, 49), impulse inhibition (50), and children's school performance (51), as well as imagination and creativity (52).

### **CONSENSUS STATEMENT #2: EVIDENCE SUPPORTS AN ASSOCIATION BETWEEN COMMON TYPES OF NATURE EXPERIENCE AND A REDUCTION OF RISK FACTORS AND BURDEN OF SOME TYPES OF MENTAL ILLNESS**

Nature experience has been associated with improved sleep (53) and reductions in stress, as assessed by self-report and various physiological measures and biomarkers of acute and chronic stress (32, 35). These impacts on sleep and stress may entail decreased risk for mental illness, as sleep problems and stress are major risk factors for mental illness, especially depression (54). In addition, there is growing evidence that nature experience is associated with a decreased incidence of other disorders [see (28, 55, 56) for reviews on the effects of green space on specific psychopathologies, including anxiety disorders (57), attention deficit and hyperactivity disorder (ADHD) (58, 59), and depression (60, 61)]. Several of these associations are moderated by various contextual and individual factors, such as socioeconomic status, gender, and age (62).

In both consensus statements above, we include studies that have demonstrated significant associations, with a range of certainty regarding correlation versus causation. It is essential that future research continues to specify and investigate underlying pathways and causal mechanisms to refine understanding of the relationships between the environment and human well-being.

### **CONSENSUS STATEMENT #3: EVIDENCE SUGGESTS THAT OPPORTUNITIES FOR SOME TYPES OF NATURE EXPERIENCE ARE DECREASING IN QUANTITY AND QUALITY FOR MANY PEOPLE AROUND THE GLOBE**

Over the past century, people have been increasingly concentrated in urban areas. In many instances, modern living habits involve reduced regular contact with outdoor nature and increased time spent indoors, on screens, and performing sedentary activities (63, 64). This disengagement from nature may be partially driven by a negative feedback loop. As direct nature experiences become progres-

sively unavailable to new generations, this creates an ever-narrowing spectrum of nature experiences (65). An “environmental generational amnesia” and “extinction of experience” (66) may stem from each generation's reduced experience of “wildness” (or increased experience of environmental pollution)—shifting the baseline of reference points for the acceptable quality, richness, and variation in nature experiences (67).

### **MOVING FORWARD: SUPPORTING MENTAL HEALTH AS AN ECOSYSTEM SERVICE**

These consensus statements underpin our conceptual model. The evidence in this arena is building to a point at which we may soon be enabled to make meaningful (even if not extremely precise) predictions regarding the impacts of environmental change on mental health. Here, we propose a way forward that harnesses existing knowledge to eventually incorporate it into ecosystem service assessments. Psychological and social processes differ from biological and geophysical processes. They exist in changing historical and cultural contexts, and even short-term changes are susceptible to multiple determinants. Given current knowledge, the model can only address average, population-level impacts, with the aim of eventually being able to distinguish and specify effects as they occur at the individual, subgroup (e.g., gender and age categories), or at-risk subpopulation (e.g., people with depression and ADHD) levels. Nonetheless, our approach is broadly guided by other ecosystem service models, insofar as we trace a pathway from environment to mental health (Fig. 1).

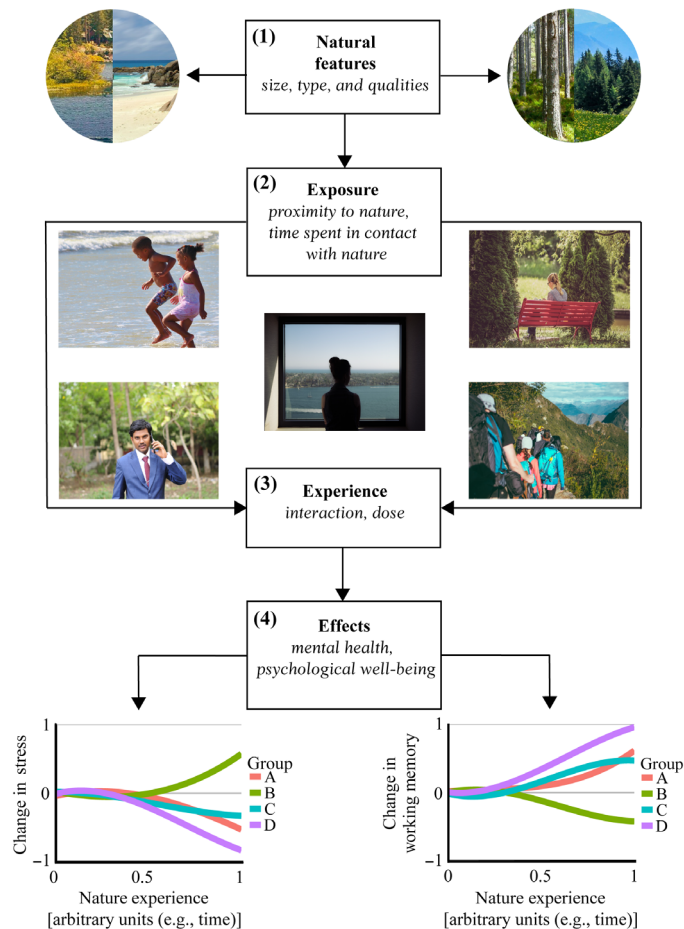
In step 1, we characterize and define “natural features” (including size, type, composition and spatial configuration, biodiversity, and other attributes of land covers/uses). In step 2, we characterize “exposure” of people to nature (and/or type of “use”) through an accounting/estimation of the proximity of this nature to people. In step 3, we illustrate some of the crucial specifics of nature exposure (i.e., nature experience) through the approaches captured in the notions of “interaction pattern” and “dose.” In step 4, we account for the mental health effects of nature experience via the translation of this nature experience into specific mental health benefits. Separately (see Box 2), we discuss what may be involved in placing a value on these benefits, in monetary or other terms.

#### **Step 1: Natural features**

This step characterizes the elements of nature potentially influencing mental health and includes size (total area), composition (proportions of different types of natural elements), and spatial configuration (e.g., degrees of fragmentation and connectivity with other green space) of natural landscapes. Other relevant natural attributes may include tree canopy density, vegetation structure, species composition, or biodiversity (68, 69). Data can be gathered from a variety of sources (e.g., remote sensing and fieldwork) and can be operationalized in different ways (e.g., land-use classification maps and databases).

Determining which aspects of natural features are relevant to mental health—and should therefore be considered in this step—is a key research frontier and will be informed through an iterative process via an evolution of insights and evidence regarding effects (see step 3). For example, are some tree species more beneficial than others (70)? Is a diversity of tree species in a forest more beneficial than a monoculture stand (71)? It is also important to note that little





**Fig. 1. A conceptual model for mental health as an ecosystem service.** (1) Natural features include the characteristics (size, type, and qualities such as configuration) of the nature under consideration. (2) Exposure is estimated through methods that take proximity, likelihood, and duration of nature contact into account. (3) Experience characterizes the types, forms, and intensity of experience that exposure instantiates. (4) Effects (i.e., mental health impacts) will vary according to the moderating influences of individual differences and sociocultural context, which may affect the impact experienced by people [here represented conceptually by groups A to D (e.g., different age groups)], members of which may receive different benefits from nature experience, given these moderators. It is also possible that a group will receive a net negative effect due to individuals' aversion to urban green spaces or the negative repercussion of green gentrification in their area, for example (represented conceptually by group B). Photographs are from the public domain and free for public use.

is known about relationships between ecological integrity or complexity and mental health benefits. It may be that places intermediate on the wild-anthropogenic spectrum, tuned to some common evolutionary-based human preferences, are associated with better mental health (72). Our lack of certainty with respect to these and other questions regarding the relationship between nature and mental health underscores the need for future research. It is also a reminder that the purpose of this endeavor is to create a conceptual model with which to integrate the best available evidence, wherever that may stand, as the field evolves. We must also consider how aspects of natural features result in various amounts of exposure, given the different opportunities for direct and indirect nature contact they afford. This is addressed in the next step.

## Box 2. Valuation and decision-making contexts.

There is a considerable literature describing the monetary valuation of mental health. Analyses have focused on the avoided costs of mental illness and on the economic benefits of happiness, well-being, and thriving. A range of methods has been used in these cases, including direct market valuation, indirect market valuation (avoided cost, factor income, hedonic pricing, etc.), and contingent valuation (106). In general, mental distress and mental illness account for considerable costs, and relief of such suffering yields large benefits for society and the individuals affected (107, 108). Improved learning and work productivity resultant from nature contact may also have positive economic impacts (109).

However, monetary value is only one of many ways to quantify the mental health benefits produced by nature exposure. Many noneconomic measures of quality of life, well-being, and happiness have been developed (110), both in clinical settings and in sustainability science, and these may have a role in valuing mental health as an ecosystem service. One example is the DALY, now a standard currency in quantifying burden of disease and potentially suitable in ecosystem services calculations. Another form of valuation includes a ranking approach (rather than absolute values) that projects the expected relative benefits of alternative scenarios of change in a specific location.

These valuation approaches can help reveal the contribution of ecosystems to mental health in decision-making. With a more complete picture, decision makers can more fully consider the repercussions of losing or enhancing access to nature, in the context of urban design, including the spatial layout of built and natural environments, and proximity to workplaces and homes. Valuation can help inform judgments of whether to invest in nature and how to do so while also considering other pressing needs. Our knowledge regarding the magnitude of mental health benefits on their own may not be enough to justify the costs associated with increasing nature within cities, but together with benefits such as water quality, flood security, urban cooling, and recreation, we can obtain a more complete picture of the impact of these types of decisions.

## Step 2: Exposure

Exposure is a broad term, here referring to the amount of contact that an individual or population has with nature. Because data on actual exposure are usually not available, especially in cases in which we are concerned with hypothetical scenarios, actual exposure is often estimated by access/availability metrics based on the presence of the types of natural features identified in step 1.

The proximity of people to nature is likely to be a large determinant of exposure. A watershed located 50 km outside a city might generate considerable ecosystem services in provision of clean water to the city but not much opportunity for everyday interaction with the landscape. Conversely, the presence of a small city park may result in extensive nature exposure for neighborhood residents and commuters.

At present, there is a limited repertoire of methods for estimating nature exposure based on geography. Ekel and de Vries (73) have identified two principal approaches: cumulative opportunity and proximity measures.

Cumulative opportunity is based on the proportion of nature within a spatial unit that incorporates individuals' location (typically a residence). Using sources such as satellite images or land-use databases, this proportion is generally calculated as the percentage of an area of interest (a zip code area, census block, etc.) that comprises natural elements (e.g., street trees, green space, and blue space). A cumulative exposure metric for a population can then be derived for a

given spatial unit based on this composition score (e.g., percentage of green space) (73). Proximity measures typically estimate use and exposure to nature as a function of direct physical distance to the nearest nature area of a certain size, usually from a place of residence. Walking time from residence to nature has also been used as a proximity measure.

These and other approaches, based primarily on estimations of average exposures, show mixed levels of reliability in their associations with health outcomes (74). As metrics are further developed, frequency and duration of exposure should be considered, as well as aspects of the natural features themselves (from step 1). For example, the composition, spatial configuration, and other features of nature will influence the amount of exposure that a population will experience (intentionally or otherwise) due to resultant differences in accessibility (Fig. 2). Other characteristics of these natural spaces (e.g., amenities, upkeep, and perceived safety), as well as park programming that is effectively tailored to neighborhood populations, may moderate the relationship between natural features and exposure through encouraging or discouraging visitation or affording opportunities for different activities (75). In future iterations of the model, we can look to methods used by recreation and cultural ecosystem service models for ways to isolate predictors of visitation to areas in a landscape (e.g., participatory Geographic Information Systems (GIS), interviews, social media data mining, and other methods) (10). Where available, primary data on actual nature exposure (versus potential or opportunity for exposure) can also be incorporated.

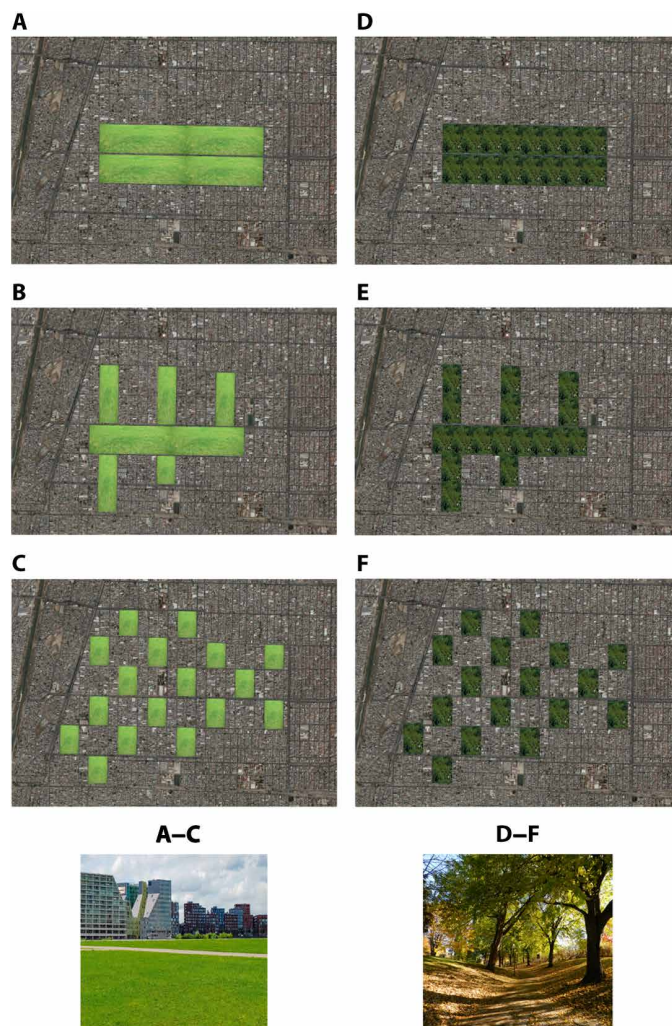
With respect to characteristics of beneficiaries, the model should eventually account for the sociodemographic, cultural, perceptual, attitudinal, and behavioral differences that influence the tendency for seeking out nature exposure (76, 77). Measurement approaches based on location alone can fail to account for differences in exposure that are due to factors such as access to transportation corridors, time demands, income disparities, and perceived safety. They can also fail to take into account the specifics of the exposure itself—an aspect that can be measured in a variety of ways, including ecological momentary assessment techniques, designed to understand peoples' psychological states in given geographical contexts (78). This consideration brings us to step 3.

### Step 3: Experience

The third step in the model accounts for the experiential characteristics of nature exposure—what we term nature experience. In moving from nature exposure to mental health effects, we need to consider these specifics. Though attuned to pragmatic considerations regarding data availability, neither cumulative opportunity nor proximity measures account for some relevant aspects of nature experience, including, for example, the sensory qualities of the exposure. Although much of the research literature defaults to eyesight as the primary modality for nature contact (79), the auditory, tactile, and olfactory modalities are also important to consider (80). Effective park programming can also have a substantial impact on the ways in which users interact with natural spaces, and thereby help determine how these sensory pathways are engaged (21). Two approaches suggest ways to classify nature exposure and characterize nature experience:

#### Interaction

The specific ways in which people interact with nature may account for differential impacts of nature exposure on mental health (40). Looking at water is different from swimming in water, for example.



**Fig. 2. Configuration and composition of urban green space.** Along with other factors, spatial configuration and composition should be considered when estimating nature exposure. Different shades of green here represent different types of nature [e.g., clusters of open lawns (A to C) versus trees (D to F)], which are embedded within urban surroundings. Despite these differences, all panels have the same total amount of nature (34 street blocks). Vertical contrasts illustrate differences in configuration of this nature [e.g., (A) versus (B) versus (C)]; horizontal contrasts illustrate differences in its composition (i.e., type of nature) [e.g., (A) versus (D)]. Images (A) to (F), ©2017 Google; images (A)–(C) and (D)–(F) are photographs from the public domain and free for public use.

One way of modeling this human-nature interaction is in terms of “interaction patterns”—a description of the meaningful ways in which human beings interact with nature, characterized at a level of abstraction such that it can be applied across different forms of nature. For example, walking along the edge of water and land can occur at the ocean or alongside a lake or river. To date, around 150 human-nature interaction patterns, with photos and descriptions for many of them, have been generated and catalogued (40, 81). Future studies can look at specific health outcomes of people who engage not only in specific forms of interaction but also in constellations of them.

#### Dose

Toxicologists distinguish between “exposure,” the amount or intensity of a physical, chemical, or other environmental agent that reaches

the target population or organism, and “absorbed (or internal) dose,” the amount taken up by an organism and/or delivered to the target organ (82). Exposure and dose can vary considerably in toxicology, if, for example, two people exposed to the same concentration of an air pollutant breathe at very different rates. A similar phenomenon may operate with respect to nature contact (83) via different levels of attention, preference, and feelings of personal connection with nature (84). People have different levels of awareness and perceptions of natural environments (85) in their attitudes and receptivity toward nature, childhood experiences, and sense of connectedness to nature—factors that probably affect the delivered dose that results from a given exposure. The transition from dose to effects corresponds to what economists call a production function, and what toxicologists and epidemiologists quantify using a dose-response curve. We discuss more on the multiple potential causal mechanisms below in step 4.

#### Step 4: Effects

The fourth and final step of our conceptual model involves a characterization of the potential mental health impacts that follow from nature experience. Epidemiologic and experimental studies have revealed a range of effects, as summarized above (see consensus statements), although most have omitted step 3, going straight from step 2 to step 4 (for exceptions, see the Supplementary Materials for references), and calculated associated effects from an exposure metric (thereby neglecting to account for “experience”). The production of mental health benefits from nature experience may occur through multiple psychological causal mechanisms and pathways, including reduction of stress, increases in social cohesion or physical activity, or replenishment of cognitive capacities, to name just a few. In many cases, the same natural area will engage multiple mechanisms during each single experience (24, 86, 87) so that the cumulative effects attributed to any single pathway may be misestimated. Current insight into each of these mechanisms is incomplete. However, the evidence regarding the effects themselves is sufficient to support some decision-making contexts (discussed below) that encourage nature contact to promote health (24, 33, 88).

As with the characteristics of exposure, the effects of nature experience will also depend on age, gender, current affective state, and other personal characteristics (e.g., preferences for nature) (35, 36, 62). The types of mental health benefits will also vary (e.g., cognitive function, mood, and stress reduction). Some will relate to psychological well-being, and others will relate to relevant factors for the onset of disease. The range of these outcomes includes population-level indicators and clinical-level measures, assessed through self-report, physiological measures, and other approaches.

#### AN EXAMPLE APPLICATION

Given the degree of complexity and the need for future iteration, it is helpful to consider an example application of this conceptual model to illustrate its potential for informing decisions regarding land use, urban planning, or environmental management (Fig. 3). We briefly describe a hypothetical decision-making context below and define the steps that one might take in applying the conceptual model. As stated above, while many factors affect health through complex pathways, this model relates only to a subset of environmental factors. In addition, we do not account here for the other potential impacts or benefits of scenarios involving planned envi-

ronmental change (e.g., planting of urban trees for heat or pollution mitigation).

Consider a decision-making context in which practitioners would like to estimate the impacts of planting residential street trees on the prevalence of mental illness. Using our model, they would initially gather information regarding the natural features of the relevant region (step 1). In this particular case, available data might consist of information on existing and proposed tree distribution, the species of trees, and perhaps some information on tree structure, likely gathered from city databases and natural history accounts. Practitioners could also deduce planned composition and configuration of the trees from consulting the planning proposals from the city. However, other aspects of the natural features (e.g., bird song, height of trees, care, and maintenance) may not be available.

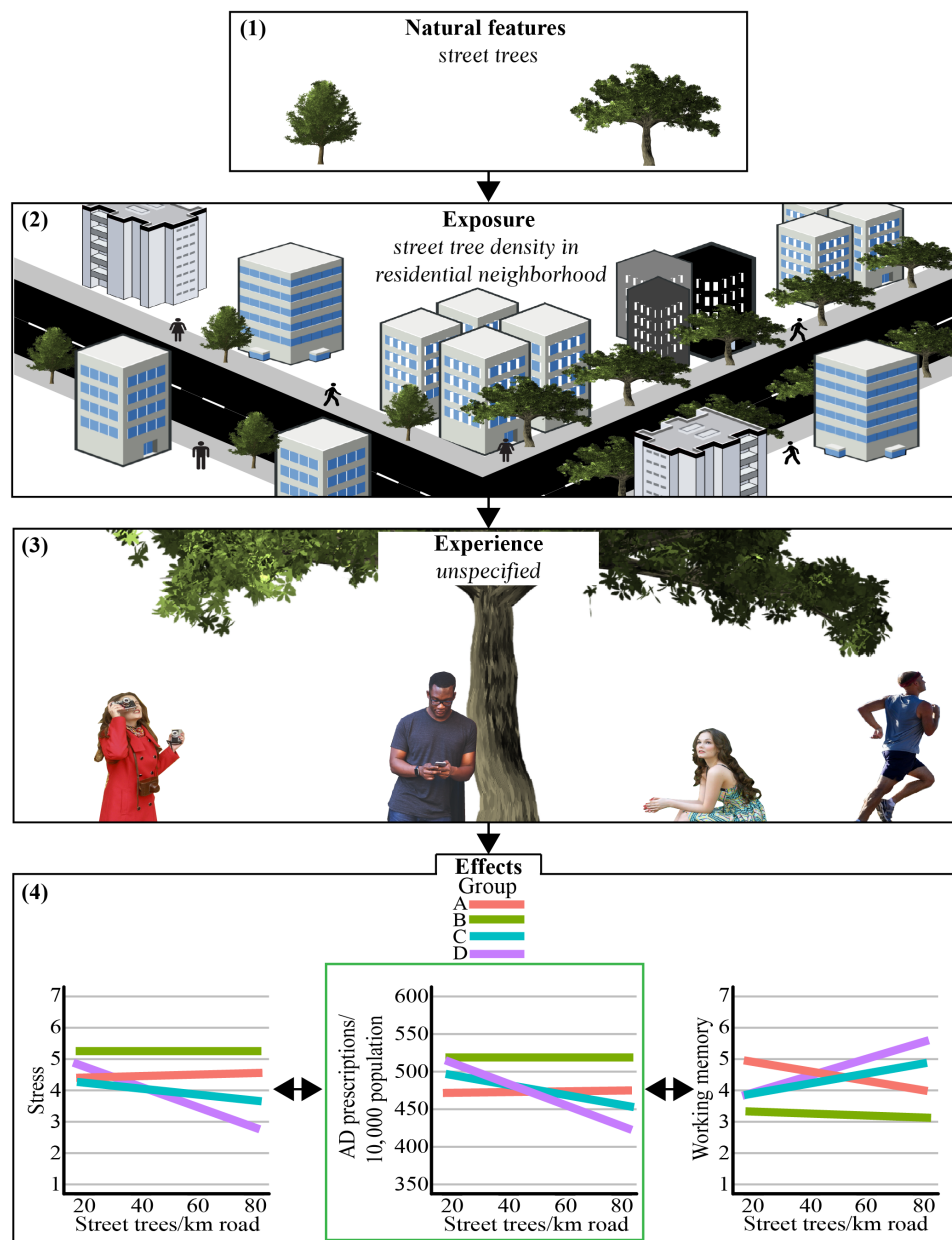
As the body of empirical research grows, practitioners could consult a central data repository containing multiple studies or meta-analyses with effect sizes documented at the relevant scale for given outcomes of interest. This would be necessary to make a prediction with any degree of certainty or scientific rigor. Continuing with the conceptual exercise, in our present example, decision makers might consider the outcome of antidepressant prescription rates as a crude proxy for depression prevalence. To do this, they could consult Taylor *et al.* (89) as an empirical study upon which to base a prediction. In this case, they would need to temper the confidence in their prediction with the knowledge that they were extrapolating from a single correlational study.

Given the approach used in this particular study, the calculation of exposure (step 2) would be based on the change in street tree density in a residential neighborhood. From this exposure metric, practitioners could then apply the association found between the density of street trees and the rate of antidepressant prescribing, in which a regression analysis indicated that each additional tree per kilometer of street was associated with 1.38 fewer antidepressant prescriptions (95% confidence interval, 0.03 to 2.72) per 1000 population per year.

Critically, we note that this rough, potential exposure metric (i.e., step 2) does not incorporate qualities addressed in step 3 (experience) into its results, as the source paper itself did not take these details into account, and we therefore cannot properly integrate these components into the calculations. Factors from other studies that do speak to mechanisms thought to mediate the relationship between the presence of street trees and the distribution and characteristics of mental health outcomes could be integrated in future iterations of the model and will almost certainly increase the accuracy and validity of the effects on a causal level. We have also not accounted for effect modification by individual- and population-level differences in potential beneficiaries. Basing predictions on simple regression analyses lacks precision. This rough calculation thus likely comes with a large degree of error, but can provide insight nonetheless, and inform decisions better than not taking mental health services into account at all.

To address effects (step 4), practitioners would calculate the number of people within the “ecoserviceshed” (i.e., the part of the landscape providing these particular ecosystem services) of the street trees. Controlling for other independent predictors of antidepressant prescription derived from Taylor *et al.* (89) (e.g., income), decision makers could then calculate a potential total benefit, defined as a decrease in antidepressant prescriptions (considered here as a crude proxy for a decrease in mental illness). It is possible then to calculate a value of this output using global estimates of the cost of depression.





**Fig. 3. A hypothetical application of the conceptual model using a case study for which antidepressant prescription is the outcome.** Information is gathered for each of the three steps. (1) Natural features in this case are street trees (other characteristics unspecified, including spatial configuration). (2) Exposure is calculated using a cumulative exposure approach regarding residential street tree density (spatial configuration illustrated here for conceptual purposes but not relevant to this estimation metric). (3) Dose and/or interaction were not taken into account. (4) The effect of decreased antidepressant (AD) prescriptions in areas with more street trees is represented along with other potential benefits (e.g., stress and working memory) not projected specifically in this case, although they are represented conceptually. As illustrated in Fig. 1, different nature options provide benefits that we can quantify over and above a “no nature” version of an urban plan. The model allows us to compare net benefits (total benefits less costs) of different viable plans. Benefits will also likely vary according to the moderating influences of individual differences and sociocultural context, here represented conceptually by groups A to D, as people receive different benefits from nature experience given these moderators. Photographs are from the public domain and free for public use.

Despite the limitations of this approach, it is possible that this prediction will be a lower bound of the total mental health benefits provided, as it is context dependent (i.e., depends on the probability that a depressed person will receive an antidepressant prescription—a feature of physician practice patterns, the health care system, and other factors), based on only one form of disorder and dimension of association (e.g., many depressed people are not diagnosed or treated,

and many more people have subclinical levels of depressive or other symptoms), and assessed with regard to one period of time. We emphasize again the intention behind this exercise, especially given the cross-sectional results upon which it is based: to give a hypothetical walkthrough of a conceptual model, the accuracy of which will be refined through successive iteration and incorporation of empirical data as they are generated by the research community.

## CONCLUSION

Diverse stakeholders, including city planners, landscape architects, engineers, parks departments, developers, infrastructure providers, health professionals, community-based organizations, and environmental advocates, could use a tool that helps them anticipate the mental health impacts of decisions they make relating to the environment. Although the magnitude and distributions of these impacts are still questions requiring further research, practitioners are nonetheless in need of the best available evidence to inform decisions that may have repercussions for mental health. Reports are beginning to be generated in response to this demand, including a recent example in which the relative value of mental health benefits was calculated to be 7% of the total economic benefits of London parks, a large fraction (amounting to ca. £6.8 billion over 30 years) given that the major economic benefit considered was higher property values (90).

With respect to general health, models are already starting to be applied within these contexts. Examples include urban tree canopy restoration to improve air quality (91), the siting of new park locations to improve physical activity (92), and efforts to use environmental investments to advance health equity (93). This last point is critical. Given the emerging evidence base for the benefits of nature contact, greater effort should be made to increase access to nature to help address the significant health inequities that people from low-opportunity neighborhoods experience, in contrast to their privileged counterparts. A greater recognition of the relationship between nature exposure and mental health is also likely to highlight income-related inequalities and provide one of many possible pathways to reduce them. Removing social and physical barriers to nature contact is an issue of environmental justice (94–98) (see the Supplementary Materials for additional references).

Throughout this paper, we have been careful to note the limitations of the evidence base today, as well as the capacity and opportunity to integrate existing evidence into predictions using a conceptual model. These limitations point to important research frontiers in (i) moving beyond correlation to causal understanding of relationships and (ii) filling priority gaps in predictive capacity through consideration of often-confounded predictors of health. A great challenge is to distinguish the nature experience signal from other (in many cases stronger) social and environmental predictors of health (lack of opportunity, insufficient amenities, racial prejudice, etc.).

Despite these limitations, we believe that there is a strong need for this type of conceptual model. Planners and practitioners are increasingly demanding the ability to account for the co-benefits of green infrastructure and other choices related to the incorporation of green space in cities or increasing access to wilderness areas outside of them. The repercussions of these choices on mental health may add up to be quite significant on a population level, and a framework is needed for their consideration and integration into decision-making today that will have influence in the decades to come.

Researchers have opportunities to add to the body of evidence through multiple pathways. First, investigators can make use of natural experiments in city greening by assessing the impact that these projects have on mental health. An excellent example of this includes a recent natural experiment that resembled a randomized control trial, in which city lots in Philadelphia underwent one of three treatments: greening versus trash removal versus control (no intervention) (99), and significantly better mental health outcomes were observed for individuals within proximity of the greening condition. Second,

researchers can run clinical trials that explicitly test the impacts of nature versus urban experience (or another comparison condition) on psychological well-being and mental health. An increasing openness to support these study designs has been demonstrated through foundations and governmental funding institutions. Third, the use of prospective cohorts and ecological momentary assessment provides a valuable context for assessing associations of within-individual change in mental health with nature contact over time using large samples of participants.

These and other situations provide opportunities to make and refine predictions of the impacts of nature contact on mental health, through a priori estimates based on emerging evidence, and a testing of the predictions through observations of actual change over time in real-world contexts. Through this iterative process, the conceptual model can evolve from its current state into an ever more robust tool for pragmatic implementation and predictive value. Ultimately, our evolving conceptual model can broaden current ecosystem service models by accounting for the effects of nature exposure on mental health, and identifying where additional green spaces or better access to nature may improve it, or where certain infrastructure, building siting, and other land-use decisions may negatively affect it. Given the large contribution of mental illness to the global burden of disease, these are essential issues to address.

With respect to modeling, mental health benefits typically co-occur with other ecosystem service benefits and may therefore be considered “co-benefits” to other services with longer research histories. These include heat-island mitigation, flood protection, and water security in cities, all of which are now being incorporated into the Natural Capital Platform (7). The development of this tool must be scrutinized critically for accuracy as it evolves. But as it continues to be refined, incorporating its outputs into land-use and urban planning decisions will enable considerations that might not otherwise be made explicit. In this way, a critical aspect of environmental impact on human well-being may be incorporated into assessments of the contributions from the natural world—and increase informed efforts to conserve and manage it (100).

## SUPPLEMENTARY MATERIALS

Supplementary material for this article is available at <http://advances.sciencemag.org/cgi/content/full/5/7/eaax0903/DC1>

Table S1. Supplementary references.

References (111–273)

## REFERENCES AND NOTES

1. G. C. Daily, *Nature's Services: Societal Dependence on Natural Ecosystems* (Island Press, 1997).
2. Millennium Ecosystem Assessment, *Ecosystems and Human Well-Being* (World Resources Institute, 2005).
3. S. Díaz, U. Pascual, M. Stenseke, B. Martin-López, R. T. Watson, Z. Molnár, R. Hill, K. M. A. Chan, I. A. Baste, K. A. Brauman, S. Polasky, A. Church, M. Lonsdale, A. Larigauderie, P. W. Leadley, A. P. E. van Oudenhoven, F. van der Plaats, M. Shröter, S. Lavorel, Y. Aumeeruddy-Thomas, E. Bukvareva, K. Davies, S. Demissew, G. Erpul, P. Failler, C. A. Guerra, C. L. Hewitt, H. Keune, S. Lindley, Y. Shirayama, Assessing nature's contributions to people. *Science* **359**, 270–272 (2018).
4. C. Li, H. Zheng, S. Li, X. Chen, J. Lie, W. Zheng, Y. Liang, S. Polasky, M. W. Feldman, M. Ruckelshaus, Z. Ouyang, G. C. Daily, Impacts of conservation and human development policy across stakeholders and scales. *Proc. Natl. Acad. Sci. U.S.A.* **112**, 7396–7401 (2015).
5. A. D. Guerry, S. Polasky, J. Lubchenco, R. Chaplin-Kramer, G. C. Daily, R. Griffin, M. Ruckelshaus, I. J. Bateman, A. Duraipapp, T. Elmqvist, M. W. Feldman, C. Folke, J. Hoekstra, P. M. Kareiva, B. L. Keeler, S. Li, E. McKenzie, Z. Ouyang, B. Reyers, T. H. Ricketts, J. Rockström, H. Tallis, B. Vira, Natural capital and ecosystem services informing decisions: From promise to practice. *Proc. Natl. Acad. Sci. U.S.A.* **112**, 7348–7355 (2015).



6. L. Mandle, Z. Ouyang, J. Salzman, G. C. Daily, *Green Growth That Works: Natural Capital Policy and Finance Mechanisms from Around the World* (Island Press, 2019).
7. P. Kareiva, H. Tallis, T. H. Ricketts, G. C. Daily, S. Polasky, *Natural Capital: Theory and Practice of Mapping Ecosystem Services: Theory and Practice of Mapping Ecosystem Services* (Oxford Univ. Press, 2011).
8. K. Brauman, G. C. Daily, T. K. Duarte, H. Mooney, The nature and value of ecosystem services: An overview highlighting hydrologic services. *Annu. Rev. Environ. Resour.* **32**, 67–98 (2007).
9. E. Lonsdorf, C. Kremen, T. Ricketts, R. Winfree, N. Williams, S. Greenleaf, Modelling pollination services across agricultural landscapes. *Ann. Bot.* **103**, 1589–1600 (2009).
10. T. C. Daniel, A. Muhar, A. Arnberger, O. Azhar, J. W. Boyd, K. M. A. Chan, R. Costanza, T. Elmqvist, C. G. Flint, P. H. Gobster, A. Grêt-Regamey, R. Lave, S. Muhar, M. Penker, R. G. Ribe, T. Schauppenlehner, T. Sikor, I. Soloviy, M. Spierenburg, K. Taczanowska, J. Tam, A. von der Dunk, Contributions of cultural services to the ecosystem services agenda. *Proc. Natl. Acad. Sci. U.S.A.* **109**, 8812–8819 (2012).
11. A. E. Van den Berg, From green space to green prescriptions: Challenges and opportunities for research and practice. *Front. Psychol.* **8**, 8–11 (2017).
12. Z. Steel, C. Marnane, C. Iranpour, T. Chey, J. W. Jackson, V. Patel, D. Silove, The global prevalence of common mental disorders: A systematic review and meta-analysis 1980–2013. *Int. J. Epidemiol.* **43**, 476–493 (2014).
13. D. Vigo, G. Thornicroft, R. Atun, Estimating the true global burden of mental illness. *Lancet Psychiatry* **3**, 171–178 (2016).
14. A. Meyer-Lindenberg, Social neuroscience and mechanisms of risk for mental disorders. *World Psychiatry* **13**, 143–144 (2014).
15. D. T. C. Cox, H. L. Hudson, D. F. Shanahan, R. A. Fuller, K. J. Gaston, The rarity of direct experiences of nature in an urban population. *Landsc. Urban Plan.* **160**, 79–84 (2017).
16. E. Glaeser, *Triumph of the City: How Our Greatest Invention Makes Us Richer, Smarter, Greener, Healthier, and Happier* (Penguin Press, 2011).
17. K. Schwarz, M. Fragkias, C. G. Boone, W. Zhou, M. McHale, J. M. Grove, J. O'Neil-Dunne, J. P. McFadden, G. L. Buckley, D. Childers, L. Ogden, S. Pincetl, D. Pataki, A. Whitmer, M. L. Cadenasso, Trees grow on money: Urban tree canopy cover and environmental justice. *PLOS ONE* **10**, e0122051 (2015).
18. M. Skår, E. Krogh, Changes in children's nature-based experiences near home: From spontaneous play to adult-controlled, planned and organised activities. *Child. Geogr.* **7**, 339–354 (2009).
19. T. Hartig, P. H. Kahn Jr., Living in cities, naturally. *Science* **352**, 938–940 (2016).
20. M. A. van den Bosch, M. H. Depledge, Healthy people with nature in mind. *BMC Public Health* **15**, 1232 (2015).
21. H. Frumkin, G. N. Bratman, S. J. Breslow, B. Cochran, P. H. Kahn Jr., J. J. Lawler, P. S. Levin, P. S. Tandon, U. Varanasi, K. L. Wolf, S. A. Wood, Nature contact and human health: A research agenda. *Environ. Health Perspect.* **125**, 075001 (2017).
22. T. Hartig, A. E. van den Berg, C. M. Hagerhall, M. Tomalak, N. Bauer, R. Hansmann, A. Ojala, E. Syngollitou, G. Carrus, A. van Herzele, S. Bell, M. T. C. Podesta, G. Waaseth, Health benefits of nature experience: Psychological, in *Forests, Trees, and Human Health*, K. Nilsson, M. Sangster, C. Gallis, T. Hartig, S. de Vries, K. Seeland, J. Schipperijn, Eds. (Springer, 2011), pp. 127–168.
23. M. P. White, S. Pahl, B. W. Wheeler, M. H. Depledge, L. E. Fleming, Natural environments and subjective wellbeing: Different types of exposure are associated with different aspects of wellbeing. *Health Place* **45**, 77–84 (2017).
24. T. Hartig, R. Mitchell, S. de Vries, H. Frumkin, Nature and health. *Annu. Rev. Public Health* **35**, 207–228 (2014).
25. C. D. Ives, M. Giusti, J. Fischer, D. J. Abson, K. Klaniecki, C. Dorninger, J. Laudan, S. Barthel, P. Abernethy, B. B. Martín-López, C. Raymond, D. Kendal, H. von Wehrden, Human–nature connection: A multidisciplinary review. *Curr. Opin. Environ. Sustain.* **26–27**, 106–113 (2017).
26. D. E. Bowler, L. M. Buyung-Ali, T. M. Knight, A. S. Pullin, A systematic review of evidence for the added benefits to health of exposure to natural environments. *BMC Public Health* **10**, 456 (2010).
27. H. Ohly, M. P. White, B. W. Wheeler, A. Bethel, O. C. Ukoumunne, V. Nikolaou, R. Garside, Attention restoration theory: A systematic review of the attention restoration potential of exposure to natural environments. *J. Toxicol. Environ. Health B. Crit. Rev.* **19**, 305–343 (2016).
28. M. van den Berg, W. Wendel-Vos, M. van Poppel, H. Kemper, W. van Mechelen, J. Maas, Health benefits of green spaces in the living environment: A systematic review of epidemiological studies. *Urban For. Urban Green.* **14**, 806–816 (2015).
29. R. Ulrich, R. Simon, B. Losito, E. Fiorito, M. Miles, M. Zelson, Stress recovery during exposure to natural and urban environments. *J. Environ. Psychol.* **11**, 201–230 (1991).
30. M. G. Berman, E. Kross, K. M. Krpan, M. K. Askren, A. Burson, P. J. Deldin, S. Kaplan, L. Sherdell, I. H. Gotlib, J. Jonides, Interacting with nature improves cognition and affect for individuals with depression. *J. Affect. Disord.* **140**, 300–305 (2012).
31. P. Aspinall, P. Mavros, R. Coyne, J. Roe, The urban brain: Analysing outdoor physical activity with mobile EEG. *Br. J. Sports Med.* **49**, 272–276 (2015).
32. T. Hartig, G. W. Evans, L. Jamner, D. Davis, T. Gärling, Tracking restoration in natural and urban field settings. *J. Environ. Psychol.* **23**, 109–123 (2003).
33. P. Dadvand, X. Bartoll, X. Basagaña, A. Dalmau-Bueno, D. Martínez, A. Ambros, M. Cirach, M. Triguero-Mas, M. Gascon, C. Borrell, M. J. Nieuwenhuijsen, Green spaces and general health: Roles of mental health status, social support, and physical activity. *Environ. Int.* **91**, 161–167 (2016).
34. M. van den Berg, M. van Poppel, I. van Kamp, S. Andrusaityte, B. Balseviciene, M. Cirach, A. Danileviciute, N. Ellis, G. Hurst, D. Masterson, G. Smith, M. Triguero-Mas, I. Uzdanaviciute, P. de Wit, W. van Mechelen, C. Gidlow, R. Grazuleviciene, M. J. Nieuwenhuijsen, H. Kruize, J. Maas, Visiting green space is associated with mental health and vitality: A cross-sectional study in four European cities. *Health Place* **38**, 8–15 (2016).
35. J. Roe, C. Thompson, P. Aspinall, M. Brewer, E. Duff, D. Miller, R. Mitchell, A. Clow, Green space and stress: Evidence from cortisol measures in deprived urban communities. *Int. J. Environ. Res. Public Health* **10**, 4086–4103 (2013).
36. B. W. Wheeler, R. Lovell, S. L. Higgins, M. P. White, I. Alcock, N. J. Osborne, K. Husk, C. Sabel, M. H. Depledge, Beyond greenspace: An ecological study of population general health and indicators of natural environment type and quality. *Int. J. Health Geogr.* **14**, 17 (2015).
37. R. J. Mitchell, E. A. Richardson, N. K. Shortt, J. R. Pearce, Neighborhood environments and socioeconomic inequalities in mental well-being. *Am. J. Prev. Med.* **49**, 80–84 (2015).
38. I. Alcock, M. P. White, R. Lovell, S. L. Higgins, N. J. Osborne, K. Husk, B. W. Wheeler, What accounts for 'England's green and pleasant land'? A panel data analysis of mental health and land cover types in rural England. *Landsc. Urban Plan.* **142**, 38–46 (2015).
39. T. Astell-Burt, X. Feng, G. S. Kolt, Mental health benefits of neighbourhood green space are stronger among physically active adults in middle-to-older age: Evidence from 260,061 Australians. *Prev. Med.* **57**, 601–606 (2013).
40. P. H. Kahn Jr., J. H. Ruckert, R. L. Severson, A. L. Reichert, E. Fowler, A nature language: An agenda to catalog, save, and recover patterns of human–nature interaction. *Ecopsychology* **2**, 59–66 (2010).
41. A. Rigolon, M. H. E. M. Browning, K. Lee, S. Shin, Access to urban green space in cities of the Global South: A systematic literature review. *Urban Sci.* **2**, 67 (2018).
42. M. P. White, I. Alcock, B. W. Wheeler, M. H. Depledge, Would you be happier living in a greener urban area? A fixed-effects analysis of panel data. *Psychol. Sci.* **24**, 920–928 (2013).
43. E. Orban, R. Sutcliffe, N. Dragano, K.-H. Jöckel, S. Moebus, Residential surrounding greenness, self-rated health and interrelations with aspects of neighborhood environment and social relations. *J. Urban Health* **94**, 158–169 (2017).
44. V. Jennings, O. Bamkole, The relationship between social cohesion and urban green space: An avenue for health promotion. *Int. J. Environ. Res. Public Health* **16**, 452 (2019).
45. L. O'Brien, A. Burls, M. Townsend, M. Ebdon, Volunteering in nature as a way of enabling people to reintegrate into society. *Perspect. Public Health* **131**, 71–81 (2011).
46. J. Roe, P. Aspinall, The restorative benefits of walking in urban and rural settings in adults with good and poor mental health. *Health Place* **17**, 103–113 (2011).
47. G. N. Bratman, G. C. Daily, B. J. Levy, J. J. Gross, The benefits of nature experience: Improved affect and cognition. *Landsc. Urban Plan.* **138**, 41–50 (2015).
48. N. M. Wells, At home with nature: Effects of “greenness” on children's cognitive functioning. *Environ. Behav.* **32**, 775–795 (2000).
49. M. P. Stevenson, T. Schilhab, P. Bentsen, Attention Restoration Theory II: A systematic review to clarify attention processes affected by exposure to natural environments. *J. Toxicol. Environ. Health B. Crit. Rev.* **21**, 227–268 (2018).
50. A. F. Taylor, F. E. Kuo, W. C. Sullivan, Views of nature and self-discipline: Evidence from inner city children. *J. Environ. Psychol.* **22**, 49–63 (2002).
51. P. Dadvand, M. J. Nieuwenhuijsen, M. Esnaola, J. Forns, X. Basagaña, M. Alvarez-Pedrerol, I. Rivas, M. López-Vicente, M. De Castro Pascual, J. Su, M. Jerrett, X. Querol, J. Sunyer, Green spaces and cognitive development in primary schoolchildren. *Proc. Natl. Acad. Sci. U.S.A.* **112**, 7937–7942 (2015).
52. P. H. Kahn Jr., S. R. Kellert, *Children and Nature: Psychological, Sociocultural, and Evolutionary Investigations* (MIT Press, 2002).
53. D. S. Grigsby-Toussaint, K. N. Turi, M. Krupa, N. J. Williams, S. R. Pandi-Perumal, G. Jean-Louis, Sleep insufficiency and the natural environment: Results from the US Behavioral Risk Factor Surveillance System survey. *Prev. Med.* **78**, 78–84 (2015).
54. C. Hammen, Stress and depression. *Annu. Rev. Clin. Psychol.* **1**, 293–319 (2005).
55. J. Roe, *Cities, Green Space, and Mental Well-Being*, Oxford Research Encyclopedia of Environmental Science (Oxford Univ. Press, 2016).
56. M. Gascon, M. Triguero-Mas, D. Martínez, P. Dadvand, J. Forns, A. Plasència, M. J. Nieuwenhuijsen, Mental health benefits of long-term exposure to residential green and blue spaces: A systematic review. *Int. J. Environ. Res. Public Health* **12**, 4354–4379 (2015).

57. S. de Vries, M. ten Have, S. van Dorsselaer, M. van Wezep, T. Hermans, R. de Graaf, Local availability of green and blue space and prevalence of common mental disorders in the Netherlands. *BJPsych. Open* **2**, 366–372 (2016).
58. J. Roe, P. Aspinall, The restorative outcomes of forest school and conventional school in young people with good and poor behaviour. *Urban For. Urban Green*. **10**, 205–212 (2011).
59. F. E. Kuo, A. Faber Taylor, A potential natural treatment for attention-deficit/hyperactivity disorder: Evidence from a national study. *Am. J. Public Health* **94**, 1580–1586 (2004).
60. H. Cohen-Cline, E. Turkheimer, G. E. Duncan, Access to green space, physical activity and mental health: A twin study. *J. Epidemiol. Community Health* **69**, 523–529 (2015).
61. K. M. M. Beyer, A. Kaltenbach, A. Szabo, S. Bogar, F. J. Nieto, K. M. Malecki, Exposure to neighborhood green space and mental health: Evidence from the Survey of the Health of Wisconsin. *Int. J. Environ. Res. Public Health* **11**, 3453–3472 (2014).
62. T. Astell-Burt, R. Mitchell, T. Hartig, The association between green space and mental health varies across the lifecourse. A longitudinal study. *J. Epidemiol. Community Health* **68**, 578–583 (2014).
63. S. L. Hofferth, Changes in American children's time—1997 to 2003. *Electron. Int. J. Time Use Res.* **6**, 26–47 (2009).
64. A. J. Atkin, K. Corder, U. Ekelund, K. Wijndaele, S. J. Griffin, E. M. F. van Sluijs, Determinants of change in children's sedentary time. *PLOS ONE* **8**, e67627 (2013).
65. J. R. Miller, Biodiversity conservation and the extinction of experience. *Trends Ecol. Evol.* **20**, 430–434 (2005).
66. M. Soga, K. J. Gaston, Extinction of experience: The loss of human-nature interactions. *Front. Ecol. Environ.* **14**, 94–101 (2016).
67. P. H. Kahn Jr., Children's affiliations with nature: Structure, development, and the problem of environmental generational amnesia, in *Children and Nature: Psychological, Sociocultural and Evolutionary Investigations*, P. H. Kahn Jr., S. R. Kellert, Eds. (MIT Press, 2002).
68. O. Kardan, P. Gozdyra, B. Misić, F. Moola, L. J. Palmer, T. Paus, M. G. Berman, Neighborhood greenspace and health in a large urban center. *Sci. Rep.* **5**, 11610 (2015).
69. P. A. Sandifer, A. E. Sutton-Grier, B. P. Ward, Exploring connections among nature, biodiversity, ecosystem services, and human health and well-being: Opportunities to enhance health and biodiversity conservation. *Ecosyst. Serv.* **12**, 1–15 (2015).
70. J. Summit, R. Sommer, Further studies of preferred tree shapes. *Environ. Behav.* **31**, 550–576 (1999).
71. T. J. Pett, A. Schwartz, K. N. Irvine, M. Dallimer, Z. G. Davies, Unpacking the people-biodiversity paradox: A conceptual framework. *Bioscience* **66**, 576–583 (2016).
72. D. Martens, H. Gutscher, N. Bauer, Walking in “wild” and “tended” urban forests: The impact on psychological well-being. *J. Environ. Psychol.* **31**, 36–44 (2011).
73. E. D. Ekkel, S. de Vries, Nearby green space and human health: Evaluating accessibility metrics. *Landsc. Urban Plan.* **157**, 214–220 (2017).
74. R. Mitchell, T. Astell-Burt, E. A. Richardson, A comparison of green space indicators for epidemiological research. *J. Epidemiol. Community Health* **65**, 853–858 (2011).
75. H. Heft, in *Innovative Approaches to Researching Landscape and Health*, C. Ward Thompson, P. Aspinall, S. Bell, Eds. (Taylor & Francis Publishing, 2010), pp. 9–32.
76. M. Dallimer, Z. G. Davies, K. N. Irvine, L. Maltby, P. H. Warren, K. J. Gaston, P. R. Armsworth, What personal and environmental factors determine frequency of urban greenspace use? *Int. J. Environ. Res. Public Health* **11**, 7977–7992 (2014).
77. S. L. Bell, C. Phoenix, R. Lovell, B. W. Wheeler, Green space, health and wellbeing: Making space for individual agency. *Health Place* **30**, 287–292 (2014).
78. H. Tost, F. A. Champagne, A. Meyer-Lindenberg, Environmental influence in the brain, human welfare and mental health. *Nat. Neurosci.* **18**, 4121–4131 (2015).
79. D. Nutsford, A. L. Pearson, S. Kingham, F. Reitsma, Residential exposure to visible blue space (but not green space) associated with lower psychological distress in a capital city. *Health Place* **39**, 70–78 (2016).
80. A. Conniff, T. Craig, A methodological approach to understanding the wellbeing and restorative benefits associated with greenspace. *Urban For. Urban Green*. **19**, 103–109 (2016).
81. P. H. Kahn Jr., T. Weiss, The importance of children interacting with big nature. *Child. Youth Environ.* **27**, 7–24 (2017).
82. J. H. Duffus, M. Nordberg, D. M. Templeton, Glossary of terms used in toxicology, 2nd edition (IUPAC Recommendations 2007). *Pure Appl. Chem.* **79**, 1153–1344 (2007).
83. D. F. Shanahan, R. Bush, K. J. Gaston, B. B. Lin, J. Dean, E. Barber, R. A. Fuller, Health benefits from nature experiences depend on dose. *Sci. Rep.* **6**, 28551 (2016).
84. F. S. Mayer, C. M. Frantz, The connectedness to nature scale: A measure of individuals' feeling in community with nature. *J. Environ. Psychol.* **24**, 503–515 (2004).
85. Y. H. Lin, C. C. Tsai, W. C. Sullivan, P. J. Chang, C. Y. Chang, Does awareness effect the restorative function and perception of street trees? *Front. Psychol.* **5**, 906 (2014).
86. A. M. Dzhambov, I. Markevych, T. Hartig, B. Tilov, Z. Arabadzhev, D. Stoyanov, P. Gatsava, D. Dimitrova, Multiple pathways link urban green- and bluespace to mental health in young adults. *Environ. Res.* **166**, 223–233 (2018).
87. A. M. Dzhambov, T. Hartig, I. Markevych, B. Tilov, D. Dimitrova, Urban residential greenspace and mental health in youth: Different approaches to testing multiple pathways yield different conclusions. *Environ. Res.* **160**, 47–59 (2018).
88. S. de Vries, S. M. E. van Dillen, P. P. Groenewegen, P. Spreeuwenberg, Streetscape greenery and health: Stress, social cohesion and physical activity as mediators. *Soc. Sci. Med.* **94**, 26–33 (2013).
89. M. S. Taylor, B. W. Wheeler, M. P. White, T. Economou, N. J. Osborne, Research note: Urban street tree density and antidepressant prescription rates—A cross-sectional study in London, UK. *Landsc. Urban Plan.* **136**, 174–179 (2015).
90. Vivid Economics, *Natural Capital Accounts for Public Green Space in London* (Vivid Economics, 2017).
91. M. Rao, L. A. George, T. N. Rosenstiel, V. Shandas, A. Dinno, Assessing the relationship among urban trees, nitrogen dioxide, and respiratory health. *Environ. Pollut.* **194**, 96–104 (2014).
92. D. M. Buchner, P. H. Gobster, Promoting active visits to parks: Models and strategies for transdisciplinary collaboration. *J. Phys. Act. Health* **4**, 536–549 (2007).
93. Willamette Partnership, City of Seattle Community Health and Infrastructure Opportunities Analysis (2017); [http://willamettepartnership.org/wp-content/uploads/2017/11/Seattle\\_Health-Opportunities-Report\\_051617-final.pdf](http://willamettepartnership.org/wp-content/uploads/2017/11/Seattle_Health-Opportunities-Report_051617-final.pdf).
94. H. E. Wright Wendel, R. K. Zarger, J. R. Mihelcic, Accessibility and usability: Green space preferences, perceptions, and barriers in a rapidly urbanizing city in Latin America. *Landsc. Urban Plan.* **107**, 272–282 (2012).
95. V. Jennings, L. Larson, J. Yun, Advancing sustainability through urban green space: Cultural ecosystem services, equity, and social determinants of health. *Int. J. Environ. Res. Public Health* **13**, 196 (2016).
96. A. Rigolon, Z. Toker, N. Gasparian, Who has more walkable routes to parks? An environmental justice study of Safe Routes to Parks in neighborhoods of Los Angeles. *J. Urban Aff.* **40**, 576–591 (2018).
97. J. A. Casey, R. Morello-Frosch, D. J. Mennitt, K. Frstrup, E. L. Ogburn, P. James, Race/ethnicity, socioeconomic status, residential segregation, and spatial variation in noise exposure in the contiguous United States. *Environ. Health Perspect.* **125**, 077017 (2017).
98. W. C. Taylor, M. F. Floyd, M. C. Whitt-Glover, J. Brooks, Environmental Justice: A framework for collaboration between the public health and parks and recreation fields to study disparities in physical activity. *J. Phys. Act. Health* **4**, S50–S63 (2016).
99. E. C. South, B. C. Hohl, M. C. Kondo, J. M. MacDonald, C. C. Branas, Effect of greening vacant land on mental health of community-dwelling adults: A cluster randomized trial. *JAMA Netw. Open* **1**, e180298 (2018).
100. P. Dolan, M. P. White, How can measures of subjective well-being be used to inform public policy? *Perspect. Psychol. Sci.* **2**, 71–85 (2007).
101. World Health Organization, *Mental Health: A State of Well-Being* (World Health Organization, 2014).
102. American Psychiatric Association, *Diagnostic and Statistical Manual of Mental Disorders* (American Psychiatric Association, ed. 5, 2013).
103. World Health Organization, *International Classification of Diseases* (World Health Organization, 2017).
104. M. Seligman, Flourish: Positive psychology and positive interventions. *Tann. Lect. Hum. Values*, 231–242 (2010).
105. G. N. Bratman, J. P. Hamilton, G. C. Daily, The impacts of nature experience on human cognitive function and mental health. *Ann. N. Y. Acad. Sci.* **1249**, 118–136 (2012).
106. T. R. Insel, Assessing the economic costs of serious mental illness. *Am. J. Psychiatry* **165**, 663–665 (2008).
107. K. Johnston, W. Westerfield, S. Momin, R. Phillippi, A. Naidoo, The direct and indirect costs of employee depression, anxiety, and emotional disorders—An employer case study. *J. Occup. Environ. Med.* **51**, 564–577 (2009).
108. S. Trautmann, J. Rehm, H.-U. Wittchen, The economic costs of mental disorders: Do our societies react appropriately to the burden of mental disorders? *EMBO Rep.* **17**, 1245–1249 (2016).
109. L. Lottrup, U. K. Stigsdotter, H. Meilby, A. G. Claudi, The workplace window view: A determinant of office workers' work ability and job satisfaction. *Landsc. Res.* **40**, 57–75 (2015).
110. R. Costanza, B. Fisher, S. Ali, C. Beer, L. Bond, R. Boumans, N. L. Danigelis, J. Dickinson, C. Elliott, J. Farley, D. Elliott Gayer, L. MacDonald Glenn, T. R. Hudspey, D. F. Mahoney, L. McCahill, B. McIntosh, B. Reed, S. Abu Turab Rizvi, D. M. Rizzo, T. Simpatico, R. Snapp, An integrative approach to quality of life measurement, research, and policy. *Surv. Perspect. Integr. Environ. Soc.* **1**, 11–15 (2008).
111. K. Tzoulas, K. Korpela, S. Venn, V. Yli-Pelkonen, A. Kaźmierczak, J. Niemela, P. James, Promoting ecosystem and human health in urban areas using green infrastructure: A literature review. *Landsc. Urban Plan.* **81**, 167–178 (2007).
112. R. Sharp, H. T. Tallis, T. Ricketts, A. D. Guerry, S. A. Wood, R. Chaplin-Kramer, E. Nelson, D. Ennaanay, S. Wolny, N. Olwero, K. Vigerstol, D. Pennington, G. Mendoza, A. Aukema, J. Foster, J. Forrest, D. Cameron, K. Arkema, E. Lonsdorf, C. Kennedy, G. Verutes, C. K. Kim, G. Guannel, M. Papenfus, J. Toft, M. Marsik, J. Bernhardt, R. Griffin, K. Glawinski, N. Chaumont, A. Perelman, M. Lacayo, L. Mandle, P. Hamel, A. L. Vogl, L. Rogers,

- W. Bierbower, D. Denu, J. Douglass, *INVEST 3.6.0 User's Guide* (The Natural Capital Project, Stanford University, University of Minnesota, The Nature Conservancy, and World Wildlife Fund, 2018).
113. M. Schaefer, E. Goldman, A. Bartuska, A. Sutton-Grier, J. Lubchenco, Nature as capital: Advancing and incorporating ecosystem services in United States federal policies and programs. *Proc. Natl. Acad. Sci. U.S.A.* **112**, 7383–7389 (2015).
  114. L. Schultz, C. Folke, H. Österblom, P. Olsson, Adaptive governance, ecosystem management, and natural capital. *Proc. Natl. Acad. Sci. U.S.A.* **112**, 7369–7374 (2015).
  115. A. J. Guswa, K. A. Brauman, C. Brown, P. Hamel, B. L. Keeler, S. S. Sayre, Ecosystem services: Challenges and opportunities for hydrologic modeling to support decision making. *Water Resour. Res.* **50**, 4535–4544 (2014).
  116. M. R. Smith, G. M. Singh, D. Mozaff, S. S. Myers, Effects of decreases of animal pollinators on human nutrition and global health: A modelling analysis. *Lancet* **386**, 1964–1972 (2015).
  117. A. E. S. Ford, H. Graham, P. C. L. White, Integrating human and ecosystem health through ecosystem services frameworks. *Ecohealth* **12**, 660–671 (2015).
  118. B. R. Bayles, K. A. Brauman, J. N. Adkins, B. F. Allan, A. M. Ellis, T. L. Goldberg, C. D. Golden, D. S. Grigsby-Toussaint, S. S. Myers, S. A. Osofsky, T. H. Ricketts, Ecosystem services connect environmental change to human health outcomes. *Ecohealth* **13**, 443–449 (2016).
  119. R. C. Buckley, P. Brough, Nature, eco, and adventure therapies for mental health and chronic disease. *Front. Public Health* **5**, 220 (2017).
  120. Y. Andersson-Sköld, J. Klingberg, B. Gunnarsson, K. Cullinane, I. Gustafsson, M. Hedblom, I. Knez, F. Lindberg, Å. O. Sang, H. Pleijel, P. Thorsson, A framework for assessing urban greenery's effects and valuing its ecosystem services. *J. Environ. Manage.* **205**, 274–285 (2018).
  121. K. K. Arkema, G. M. Verutes, S. A. Wood, C. Clarke-Samuels, S. Rosado, M. Canto, A. Rosenthal, M. Ruckelshaus, G. Guannel, J. Toft, J. Faries, J. M. Silver, R. Griffin, A. D. Guerry, Embedding ecosystem services in coastal planning leads to better outcomes for people and nature. *Proc. Natl. Acad. Sci. U.S.A.* **112**, 7390–7395 (2015).
  122. L. Scarlett, J. Boyd, Ecosystem services and resource management: Institutional issues, challenges, and opportunities in the public sector. *Ecol. Econ.* **115**, 3–10 (2013).
  123. R. S. de Groot, M. A. Wilson, R. M. J. Boumans, A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecol. Econ.* **41**, 393–408 (2002).
  124. D. E. Bloom, E. Cafiero, E. Jané-Llopis, S. Abrahams-Gessel, L. R. Bloom, S. Fathima, A. B. Feigl, T. Gaziano, A. Hamandi, M. Mowafi, D. O'Farrell, *The Global Economic Burden of Noncommunicable Diseases* (World Economic Forum, 2011).
  125. P. Y. Collins, V. Patel, S. S. Joestl, D. March, T. R. Insel, A. S. Daar, I. A. Bordin, E. J. Costello, M. Durkin, C. Fairburn, R. I. Glass, W. Hall, Y. Huang, S. E. Hyman, K. Jamison, S. Kaaya, S. Kapur, A. Kleinman, A. Ogunniyi, A. Otero-Ojeda, M.-M. Poo, V. Ravindranath, B. J. Sahakian, S. Saxena, P. A. Singer, D. J. Stein, Grand challenges in global mental health. *Nature* **475**, 27–30 (2011).
  126. GBD 2016 Disease and Injury Incidence and Prevalence Collaborators, Global, regional, and national incidence, prevalence, and years lived with disability for 328 diseases and injuries for 195 countries, 1990–2016: A systematic analysis for the Global Burden of Disease Study 2016. *Lancet* **390**, 1211–1259 (2017).
  127. GBD 2016 DALYs and HALE Collaborators, Global, regional, and national disability-adjusted life-years (DALYs) for 333 diseases and injuries and healthy life expectancy (HALE) for 195 countries and territories, 1990–2016: A systematic analysis for the Global Burden of Disease Study 2016. *Lancet* **390**, 1260–1344 (2017).
  128. J. Allen, R. Balfour, R. Bell, M. Marmot, Social determinants of mental health. *Int. Rev. Psychiatry* **26**, 392–407 (2014).
  129. J. T. Cacioppo, D. G. Amaral, J. J. Blanchard, J. L. Cameron, C. S. Carter, D. Crews, S. Fiske, T. Heatherton, M. K. Johnson, M. J. Kozak, R. W. Levenson, C. Lord, E. K. Miller, K. Ochsner, M. E. Raichle, M. T. Shea, S. E. Taylor, L. J. Young, K. J. Quinn, Social neuroscience: Progress and implications for mental health. *Perspect. Psychol. Sci.* **2**, 99–123 (2007).
  130. E. J. Nestler, C. J. Peña, M. Kundakovic, A. Mitchell, S. Akbarian, Epigenetic basis of mental illness. *Neuroscientist* **22**, 447–463 (2016).
  131. S. J. H. Biddle, M. Asare, Physical activity and mental health in children and adolescents: A review of reviews. *Br. J. Sports Med.* **45**, 886–895 (2011).
  132. W. T. Boyce, M. S. Kobar, Development and the epigenome: The "synapse" of gene-environment interplay. *Dev. Sci.* **18**, 1–23 (2015).
  133. P. Dolan, T. Peasgood, M. White, Do we really know what makes us happy? A review of the economic literature on the factors associated with subjective well-being. *J. Econ. Psychol.* **29**, 94–122 (2008).
  134. World Health Organization, Mental health: Facing the challenges, building solutions, in *Proceedings from the WHO European Ministerial Conference* (WHO, 2005).
  135. World Health Organization, *Promoting Mental Health: Concepts, Emerging Evidence, Practice* (World Health Organization, 2005).
  136. World Health Organization, *Mental Health and Older Adults* (World Health Organization, 2013).
  137. W. Lutz, W. Sanderson, S. Scherbov, The coming acceleration of global population ageing. *Nature* **451**, 716–719 (2008).
  138. United Nations, *World Population Ageing* (United Nations Department of Economic and Social Affairs, Population Division, 2017).
  139. F. Landeiro, P. Barrows, E. Nuttall Musson, A. M. Gray, J. Leal, Reducing social isolation and loneliness in older people: A systematic review protocol. *BMJ Open* **7**, e013778 (2017).
  140. R. Ibrahim, Y. Abolfathi Momtaz, T. A. Hamid, Social isolation in older Malaysians: Prevalence and risk factors. *Psychogeriatrics* **13**, 71–79 (2013).
  141. C. R. Victor, S. J. Scambler, A. Bowling, J. Bond, The prevalence of, and risk factors for, loneliness in later life: A survey of older people in Great Britain. *Ageing Soc.* **25**, 357–375 (2005).
  142. P. C. Hallal, L. B. Andersen, F. C. Bull, R. Guthold, W. Haskell, U. Ekelund; Lancet Physical Activity Series Working Group, Global physical activity levels: Surveillance progress, pitfalls, and prospects. *Lancet* **380**, 247–257 (2012).
  143. K. Wilhelm, L. Wedgwood, G. Parker, L. Geerlings, D. Hadzi-Pavlovic, Predicting mental health and well-being in adulthood. *J. Nerv. Ment. Dis.* **198**, 85–90 (2010).
  144. P. J. Lucassen, P. Meerlo, A. S. Naylor, A. M. van Dam, A. G. Dayer, E. Fuchs, C. A. Oomen, B. Czéh, Regulation of adult neurogenesis by stress, sleep disruption, exercise and inflammation: Implications for depression and antidepressant action. *Eur. Neuropsychopharmacol.* **20**, 1–17 (2010).
  145. X. Fan, D. C. Goff, D. C. Henderson, Inflammation and schizophrenia. *Expert Rev. Neurother.* **7**, 789–796 (2014).
  146. A. Rigolon, J. Németh, Privately owned parks in new urbanist communities: A study of environmental privilege, equity, and inclusion. *J. Urban Aff.* **40**, 543–559 (2018).
  147. S. M. Landry, J. Chakraborty, Street trees and equity: Evaluating the spatial distribution of an urban amenity. *Environ. Plan. A Econ. Space* **41**, 2651–2670 (2009).
  148. S. Gentin, Outdoor recreation and ethnicity in Europe—A review. *Urban For. Urban Green.* **10**, 153–161 (2011).
  149. N. Heynen, H. A. Perkins, P. Roy, The political ecology of uneven urban green space: The impact of political economy on race and ethnicity in producing environmental inequality in Milwaukee. *Urban Aff. Rev.* **42**, 3–25 (2016).
  150. J. R. Wolch, J. Byrne, J. P. Newell, Urban green space, public health, and environmental justice: The challenge of making cities 'just green enough'. *Landsch. Urban Plan.* **125**, 234–244 (2014).
  151. N. Kabisch, D. Haase, M. A. van den Bosch, Adding natural areas to social indicators of intra-urban health inequalities among children: A case study from Berlin, Germany. *Int. J. Environ. Res. Public Health* **13**, 783 (2016).
  152. H. J. Lee, D. K. Lee, Do sociodemographic factors and urban green space affect mental health outcomes among the urban elderly population? *Int. J. Environ. Res. Public Health* **16**, 789 (2019).
  153. H. Frumkin, Beyond toxicity: Human health and the natural environment. *Am. J. Prev. Med.* **20**, 234–240 (2001).
  154. R. Bosurgi, R. Horton, The Lancet Planetary Health: A new journal for a new discipline—A call for papers. *Lancet* **389**, 139 (2017).
  155. M. C. Kondo, J. M. Fluehr, T. McKeon, C. C. Branas, Urban green space and its impact on human health. *Int. J. Environ. Res. Public Health* **15**, 445 (2018).
  156. K. C. Fong, J. E. Hart, P. James, A review of epidemiologic studies on greenness and health: Updated literature through 2017. *Curr. Environ. Health Rep.* **5**, 77–87 (2018).
  157. L. E. Keniger, K. J. Gaston, K. N. Irvine, R. A. Fuller, What are the benefits of interacting with nature? *Int. J. Environ. Res. Public Health* **10**, 913–935 (2013).
  158. G.-J. Vanaken, M. Danckaerts, Impact of green space exposure on children's and adolescents' mental health: A systematic review. *Int. J. Environ. Res. Public Health* **15**, 2668 (2018).
  159. B. L. Keeler, P. Hamel, T. McPhearson, M. H. Hamann, M. L. Donahue, K. A. M. Prado, K. K. Arkema, G. N. Bratman, K. A. Brauman, J. C. Finlay, A. D. Guerry, S. E. Hobbie, J. A. Johnson, G. K. MacDonald, R. I. McDonald, N. Neverisky, S. A. Wood, Social-ecological and technological factors moderate the value of urban nature. *Nat. Sustain.* **2**, 29–38 (2019).
  160. R. Berto, Exposure to restorative environments helps restore attentional capacity. *J. Environ. Psychol.* **25**, 249–259 (2005).
  161. V. F. Gladwell, D. K. Brown, J. L. Barton, M. P. Tarvainen, P. Kuoppa, J. Pretty, J. M. Suddaby, G. R. H. Sandercock, The effects of views of nature on autonomic control. *Eur. J. Appl. Physiol.* **112**, 3379–3386 (2012).
  162. M. Annerstedt, P. Jönsson, M. Wallergård, G. Johansson, B. Karlson, P. Grahm, Å. M. Hansen, P. Währborg, Inducing physiological stress recovery with sounds of nature in a virtual reality forest—Results from a pilot study. *Physiol. Behav.* **118**, 240–250 (2013).
  163. B. W. Wheeler, M. White, W. Stahl-Timmins, M. H. Depledge, Does living by the coast improve health and wellbeing? *Health Place* **18**, 1198–1201 (2012).



164. M. Annerstedt, P.-O. Östergren, J. Björk, P. Grahn, E. Skärbäck, P. Währborg, Green qualities in the neighbourhood and mental health—results from a longitudinal cohort study in Southern Sweden. *BMC Public Health* **12**, 337 (2012).
165. E. A. McMahon, D. Estes, The effect of contact with natural environments on positive and negative affect: A meta-analysis. *J. Positive Psychol.* **10**, 507–519 (2015).
166. J. S. Ward, J. S. Duncan, A. Jarden, T. Stewart, The impact of children's exposure to greenspace on physical activity, cognitive development, emotional wellbeing, and ability to appraise risk. *Health Place* **40**, 44–50 (2016).
167. K. Seeland, S. Dübendorfer, R. Hansmann, Making friends in Zurich's urban forests and parks: The role of public green space for social inclusion of youths from different cultures. *Forest Policy Econ.* **11**, 10–17 (2009).
168. K. Peters, B. Elands, A. Buijs, Social interactions in urban parks: Stimulating social cohesion? *Urban For. Urban Green.* **9**, 93–100 (2010).
169. J. W. Zhang, P. K. Piff, R. Iyer, S. Koleva, D. Keltner, An occasion for unselfing: Beautiful nature leads to prosociality. *J. Environ. Psychol.* **37**, 61–72 (2014).
170. R. S. Ulrich, Visual landscapes and psychological well-being. *Landsc. Res.* **4**, 17–23 (1979).
171. F. Lymeus, T. Lundgren, T. Hartig, Attentional effort of beginning mindfulness training is offset with practice directed toward images of natural scenery. *Environ. Behav.* **49**, 536–559 (2016).
172. T. Hartig, H. Jahncke, Letter to the editor: Attention restoration in natural environments: Mixed mythical metaphors for meta-analysis. *J. Toxicol. Environ. Health B Crit. Rev.* **20**, 305–315 (2017).
173. C.-D. Wu, E. McNeely, J. G. Cedeño-Laurent, W.-C. Pan, G. Adamkiewicz, F. Dominici, S.-C. C. Lung, H.-J. Su, J. D. Spengler, Linking student performance in Massachusetts elementary schools with the "greenness" of school surroundings using remote sensing. *PLOS ONE* **9**, e108548 (2014).
174. M. G. Berman, J. Jonides, S. Kaplan, The cognitive benefits of interacting with nature. *Psychol. Sci.* **19**, 1207–1212 (2008).
175. H. Frumkin, The evidence of nature and the nature of evidence. *Am. J. Prev. Med.* **44**, 196–197 (2013).
176. E. Largo-Wight, W. W. Chen, V. Dodd, R. Weiler, Healthy workplaces: The effects of nature contact at work on employee stress and health. *Public Health Rep.* **126**, 124–130 (2011).
177. Y. Fan, K. V. Das, Q. Chen, Neighborhood green, social support, physical activity, and stress: Assessing the cumulative impact. *Health Place* **17**, 1202–1211 (2011).
178. B. Jiang, D. Li, L. Larsen, W. Sullivan, A dose-response curve describing the relationship between urban tree cover density and self-reported stress recovery. *Environ. Behav.* **48**, 607–629 (2014).
179. R. Grazuleviciene, A. Dedele, A. Danileviciute, J. Vencloviene, T. Grazulevicius, S. Andrusaityte, I. Uzdananaviciute, M. J. Nieuwenhuijsen, The influence of proximity to city parks on blood pressure in early pregnancy. *Int. J. Environ. Res. Public Health* **11**, 2958–2972 (2014).
180. M. Toda, R. Den, M. Hasegawa-Ohira, K. Morimoto, Effects of woodland walking on salivary stress markers cortisol and chromogranin A. *Complement. Ther. Med.* **21**, 29–34 (2013).
181. R. S. Ulrich, Human responses to vegetation and landscapes. *Landsc. Urban Plan.* **13**, 29–44 (1986).
182. D. K. Brown, J. L. Barton, V. F. Gladwell, Viewing nature scenes positively affects recovery of autonomic function following acute-mental stress. *Environ. Sci. Technol.* **47**, 5562–5569 (2013).
183. A. I. Egorov, S. M. Griffin, R. R. Converse, J. N. Styles, E. A. Sams, A. Wilson, L. E. Jackson, T. J. Wade, Vegetated land cover near residence is associated with reduced allostatic load and improved biomarkers of neuroendocrine, metabolic and immune functions. *Environ. Res.* **158**, 508–521 (2017).
184. J. Maas, R. A. Verheij, S. de Vries, P. Spreeuwenberg, F. G. Schellevis, P. P. Groenewegen, Morbidity is related to a green living environment. *J. Epidemiol. Community Health* **63**, 967–973 (2009).
185. D. Nutsford, A. L. Pearson, S. Kingham, An ecological study investigating the association between access to urban green space and mental health. *Public Health* **127**, 1005–1011 (2013).
186. E. Amoly, P. Davdand, J. Forns, M. López-Vicente, X. Basagaña, J. Julvez, M. Alvarez-Pedrerol, M. J. Nieuwenhuijsen, J. Sunyer, Green and blue spaces and behavioral development in Barcelona schoolchildren: The BREATHE Project. *Environ. Health Perspect.* **122**, 1351–1358 (2014).
187. I. Markevych, C. M. T. Tiesler, E. Fuentes, M. Romanos, P. Davdand, M. J. Nieuwenhuijsen, D. Berdel, S. Koletzko, J. Heinrich, Access to urban green spaces and behavioural problems in children: Results from the GINIplus and LISAplus studies. *Environ. Int.* **71**, 29–35 (2014).
188. R. Reklaitiene, R. Grazuleviciene, A. Dedele, D. Virviciute, J. Vensloviene, A. Tamosiunas, M. Baceviciene, D. Luksiene, L. Sapranaviciute-Zabazlajeva, R. Radisauskas, G. Bernotiene, M. Bobak, M. J. Nieuwenhuijsen, The relationship of green space, depressive symptoms and perceived general health in urban population. *Scand. J. Public Health* **42**, 669–676 (2014).
189. R. R. C. McEachan, S. L. Prady, G. Smith, L. Fairley, B. Cabieses, C. Gidlow, J. Wright, P. Davdand, D. van Gent, M. J. Nieuwenhuijsen, The association between green space and depressive symptoms in pregnant women: Moderating roles of socioeconomic status and physical activity. *J. Epidemiol. Community Health* **70**, 253–259 (2016).
190. A. E. van den Berg, C. G. van den Berg, A comparison of children with ADHD in a natural and built setting. *Child Care Health Dev.* **37**, 430–439 (2011).
191. A. F. Taylor, F. E. Kuo, Could exposure to everyday green spaces help treat ADHD? Evidence from children's play settings. *Appl. Psychol. Health Well Being* **3**, 281–303 (2011).
192. A. F. Taylor, F. E. M. Kuo, C. Spencer, M. Blades, in *Children and their Environments: Learning, Using and Designing Spaces* (Cambridge Univ. Press, 2006), pp. 124–139.
193. R. F. Banay, P. James, J. E. Hart, L. D. Kubzansky, D. Spiegelman, O. I. Okereke, J. D. Spengler, F. Laden, Greenness and depression incidence among older women. *Environ. Health Perspect.* **127**, 027001 (2019).
194. O. R. W. Pergams, P. A. Zaradic, Is love of nature in the US becoming love of electronic media? 16-year downtrend in national park visits explained by watching movies, playing video games, internet use, and oil prices. *J. Environ. Manage.* **80**, 387–393 (2006).
195. N. E. Klepeis, W. C. Nelson, W. R. Ott, J. P. Robinson, A. M. Tsang, P. Switzer, J. V. Behar, S. C. Hern, W. H. Engelmann, The National Human Activity Pattern Survey (NHAPS): A resource for assessing exposure to environmental pollutants. *J. Expo. Anal. Environ. Epidemiol.* **11**, 231–252 (2001).
196. R. Clements, An investigation of the status of outdoor play. *Contemp. Issues Early Child.* **5**, 68–80 (2016).
197. R. A. Fuller, K. N. Irvine, P. Devine-Wright, P. H. Warren, K. J. Gaston, Psychological benefits of greenspace increase with biodiversity. *Biol. Lett.* **3**, 390–394 (2007).
198. R. Lovell, B. W. Wheeler, S. L. Higgins, K. N. Irvine, M. H. Depledge, A systematic review of the health and well-being benefits of biodiverse environments. *J. Toxicol. Environ. Health B Crit. Rev.* **17**, 1–20 (2014).
199. I. Markevych, J. Schoierer, T. Hartig, A. Chudnovsky, P. Hystad, A. M. Dzhambov, S. de Vries, M. Triguero-Mas, M. Brauer, M. J. Nieuwenhuijsen, G. Lupp, E. A. Richardson, T. Astell-Burt, D. Dimitrova, X. Feng, M. Sadeh, M. Standl, J. Heinrich, E. Fuentes, Exploring pathways linking greenspace to health: Theoretical and methodological guidance. *Environ. Res.* **158**, 301–317 (2017).
200. M. Dallimer, K. N. Irvine, A. M. J. Skinner, Z. G. Davies, J. R. Rouquette, L. L. Maltby, P. H. Warren, P. R. Armsworth, K. J. Gaston, Biodiversity and the feel-good factor: Understanding associations between self-reported human well-being and species richness. *Bioscience* **62**, 47–55 (2012).
201. J. Dean, K. van Dooren, P. Weinstein, Does biodiversity improve mental health in urban settings? *Med. Hypotheses* **76**, 877–880 (2011).
202. T. Gerstenberg, M. Hofmann, Perception and preference of trees: A psychological contribution to tree species selection in urban areas. *Urban For. Urban Green.* **15**, 103–111 (2016).
203. S. W. MacFaden, J. P. M. O'Neil-Dunne, A. R. Royar, J. W. T. Lu, A. G. Rundle, High-resolution tree canopy mapping for New York City using LIDAR and object-based image analysis. *J. Appl. Remote Sens.* **6**, –063567 (2012).
204. M. Annerstedt van den Bosch, P. Mudu, V. Uscila, M. Barrdahl, A. Kulinka, B. Staatsen, W. Swart, H. Kruijs, I. Zurlyte, A. I. Egorov, Development of an urban green space indicator and the public health rationale. *Scand. J. Public Health* **44**, 159–167 (2015).
205. T. Pliakas, S. Hawkesworth, R. J. Silverwood, K. Nanchahal, C. Grundy, B. Armstrong, J. P. Casas, R. W. Morris, P. Wilkinson, K. Lock, Optimising measurement of health-related characteristics of the built environment: Comparing data collected by foot-based street audits, virtual street audits and routine secondary data sources. *Health Place* **43**, 75–84 (2017).
206. C.-H. Ho, V. Sasidharan, W. Elmendorf, F. K. Willits, A. Graefe, G. Godbey, Gender and ethnic variations in urban park preferences, visitation, and perceived benefits. *J. Leis. Res.* **37**, 281–306 (2005).
207. K. N. Irvine, S. L. Warber, P. Devine-Wright, K. J. Gaston, Understanding urban green space as a health resource: A qualitative comparison of visit motivation and derived effects among park users in sheffield, UK. *Int. J. Environ. Res. Public Health* **10**, 417–442 (2013).
208. K. J. Bagstad, J. M. Reed, D. J. Semmens, B. C. Sherrouse, A. Troy, Linking biophysical models and public preferences for ecosystem service assessments: A case study for the Southern Rocky Mountains. *Reg. Environ. Change* **16**, 2005–2018 (2015).
209. G. Brown, The relationship between social values for ecosystem services and global land cover: An empirical analysis. *Ecosyst. Serv.* **5**, 58–68 (2013).
210. G. Brown, V. Helene Hausner, E. Lægred, Physical landscape associations with mapped ecosystem values with implications for spatial value transfer: An empirical study from Norway. *Ecosyst. Serv.* **15**, 19–34 (2015).
211. S. Hashimoto, S. Nakamura, O. Saito, R. Kohsaka, C. Kamiyama, M. Tomiyoshi, T. Kishioka, Mapping and characterizing ecosystem services of social-ecological production landscapes: Case study of Noto, Japan. *Sustain. Sci.* **10**, 257–273 (2015).

212. T. Plieninger, S. Dijks, E. Oteros-Rozas, C. Bieling, Assessing, mapping, and quantifying cultural ecosystem services at community level. *Land Use Policy* **33**, 118–129 (2013).
213. J. P. Schägner, L. Brander, J. Maes, M. L. Paracchini, V. Hartje, Mapping recreational visits and values of European National Parks by combining statistical modelling and unit value transfer. *J. Nat. Conserv.* **31**, 71–84 (2016).
214. B. C. Sherrouse, J. M. Clement, D. J. Semmens, A GIS application for assessing, mapping, and quantifying the social values of ecosystem services. *Appl. Geogr.* **31**, 748–760 (2011).
215. R. D. Swetnam, B. Fisher, B. P. Mbilinyi, P. K. T. Munishi, S. Willcock, T. Ricketts, S. Mwakalila, A. Balmford, N. D. Burgess, A. R. Marshall, S. L. Lewis, Mapping socio-economic scenarios of land cover change: A GIS method to enable ecosystem service modelling. *J. Environ. Manage.* **92**, 563–574 (2011).
216. L. Szűcs, U. Anders, R. Bürger-Arndt, Assessment and illustration of cultural ecosystem services at the local scale—A retrospective trend analysis. *Ecol. Indic.* **50**, 120–134 (2015).
217. S. T. Doherty, C. J. Lemieux, C. Canally, Tracking human activity and well-being in natural environments using wearable sensors and experience sampling. *Soc. Sci. Med.* **106**, 83–92 (2014).
218. R. A. Fuller, K. J. Gaston, The scaling of green space coverage in European cities. *Biol. Lett.* **5**, 352–355 (2009).
219. C. D. Ives, C. Oke, A. Hehir, A. Gordon, Y. Wang, S. A. Bekessy, Capturing residents' values for urban green space: Mapping, analysis and guidance for practice. *Landsc. Urban Plan.* **161**, 32–43 (2017).
220. D. F. Shanahan, D. T. C. Cox, R. A. Fuller, S. Hancock, B. B. Lin, K. Anderson, R. Bush, K. J. Gaston, Variation in experiences of nature across gradients of tree cover in compact and sprawling cities. *Landsc. Urban Plan.* **157**, 231–238 (2017).
221. A. van Herzele, T. Wiedemann, A monitoring tool for the provision of accessible and attractive urban green spaces. *Landsc. Urban Plan.* **63**, 109–126 (2003).
222. A. Akpinar, C. Barbosa-Leiker, K. R. Brooks, Does green space matter? Exploring relationships between green space type and health indicators. *Urban For. Urban Green.* **20**, 407–418 (2016).
223. G. Brown, M. F. Schebella, D. Weber, Using participatory GIS to measure physical activity and urban park benefits. *Landsc. Urban Plan.* **121**, 34–44 (2014).
224. B. B. Lin, K. J. Gaston, R. A. Fuller, D. Wu, R. Bush, D. F. Shanahan, How green is your garden?: Urban form and socio-demographic factors influence yard vegetation, visitation, and ecosystem service benefits. *Landsc. Urban Plan.* **157**, 239–246 (2017).
225. S. A. Wood, A. D. Guerry, J. M. Silver, M. Lacayo, Using social media to quantify nature-based tourism and recreation. *Sci. Rep.* **3**, 2976 (2013).
226. K.-T. Han, Influence of limitedly visible leafy indoor plants on the psychology, behavior, and health of students at a junior high school in Taiwan. *Environ. Behav.* **41**, 658–692 (2008).
227. O. Kardan, E. Demiralp, M. C. Hout, M. R. Hunter, H. Karimi, T. Hanayik, G. Yourganov, J. Jonides, M. G. Berman, Is the preference of natural versus man-made scenes driven by bottom-up processing of the visual features of nature? *Front. Psychol.* **6**, 471 (2015).
228. B.-S. Kweon, C. D. Ellis, S.-W. Lee, G. O. Rogers, Large-scale environmental knowledge: Investigating the relationship between self-reported and objectively measured physical environments. *Environ. Behav.* **38**, 72–91 (2006).
229. C. I. Seresinhe, T. Preis, H. S. Moat, Quantifying the impact of scenic environments on health. *Sci. Rep.* **5**, 16899 (2015).
230. R. Cervinka, K. Röderer, E. Hefler, Are nature lovers happy? On various indicators of well-being and connectedness with nature. *J. Health Psychol.* **17**, 379–388 (2012).
231. J. L. Perrin, V. A. Benassi, The connectedness to nature scale: A measure of emotional connection to nature? *J. Environ. Psychol.* **29**, 434–440 (2009).
232. L. Wood, P. Hooper, S. Foster, F. Bull, Public green spaces and positive mental health—Investigating the relationship between access, quantity and types of parks and mental wellbeing. *Health Place* **48**, 63–71 (2017).
233. C. Ordóñez-Barona, How different ethno-cultural groups value urban forests and its implications for managing urban nature in a multicultural landscape: A systematic review of the literature. *Urban For. Urban Green.* **26**, 65–77 (2017).
234. J. Honold, T. Lakes, R. Beyer, E. van der Meer, Restoration in urban spaces: Nature views from home, greenways, and public parks. *Environ. Behav.* **48**, 796–825 (2015).
235. S. Feld, in *Keywords in Sound*, D. Novak, M. Sakakeeny, Eds. (2015), pp. 12–21.
236. B.-J. Park, K. Furuya, T. Kasetani, N. Takayama, T. Kagawa, Y. Miyazaki, Relationship between psychological responses and physical environments in forest settings. *Landsc. Urban Plan.* **102**, 24–32 (2011).
237. P. H. J. Kahn, J. H. Ruckert, P. H. Hasbach, in *Ecopsychology: Science, Totems, and the Technological Species*, P. H. J. Kahn, P. H. Hasbach, Eds. (MIT Press, 2012), pp. 55–77.
238. P. H. J. Kahn, E. M. Lev, S. P. Perrins, T. Weiss, T. Ehrlich, D. S. Feinberg, Human-nature interaction patterns: Constituents of a nature language for environmental sustainability. *J. Biourbanism* **1–2**, 41–57 (2018).
239. J. Hinds, P. Sparks, Engaging with the natural environment: The role of affective connection and identity. *J. Environ. Psychol.* **28**, 109–120 (2008).
240. R. Bragg, C. Wood, J. Barton, J. Pretty, Measuring connection to nature in children: A robust methodology for the RSPB (2013); <http://www.rspb.org.uk/forprofessionals/policy/education/research/connection-to-nature.aspx>.
241. K. Lachowycz, A. P. Jones, Towards a better understanding of the relationship between greenspace and health: Development of a theoretical framework. *Landsc. Urban Plan.* **118**, 62–69 (2013).
242. D. F. Shanahan, B. B. Lin, R. Bush, K. J. Gaston, J. H. Dean, E. Barber, R. A. Fuller, Toward improved public health outcomes from urban nature. *Am. J. Public Health* **105**, 470–477 (2015).
243. P. Groenewegen, A. van den Berg, J. Maas, R. A. Verheij, S. de Vries, Is a green residential environment better for health? If so, why? *Ann. Assoc. Am. Geogr.* **102**, 996–1003 (2012).
244. B. Balseviciene, L. Sinkariova, R. Grazuleviciene, S. Andrusaityte, I. Uzdanaviciute, A. Dedele, M. J. Nieuwenhuijsen, Impact of residential greenness on preschool children's emotional and behavioral problems. *Int. J. Environ. Res. Public Health* **11**, 6757–6770 (2014).
245. M. Sreetheran, C. C. K. van den Bosch, A socio-ecological exploration of fear of crime in urban green spaces—A systematic review. *Urban For. Urban Green.* **13**, 1–18 (2014).
246. W. C. Sullivan, R. Kaplan, Nature! Small steps that can make a big difference. *HERD Health Environ. Res. Des. J.* **9**, 6–10 (2015).
247. R. Y. Hsia, M. L. Belfer, A framework for the economic analysis of child and adolescent mental disorders. *Int. Rev. Psychiatry* **20**, 251–259 (2009).
248. M. Knapp, V. Lemmi, The economic case for better mental health, in *Annual Report of the Chief Medical Officer 2013, Public Mental Health Priorities: Investing in the Evidence*, S. Davies, Ed. (Department of Health, 2014), pp. 147–156.
249. R. L. DuPont, D. P. Rice, L. S. Miller, S. S. Shiraki, C. R. Rowland, H. J. Harwood, Economic costs of anxiety disorders. *Anxiety* **2**, 167–172 (1996).
250. F. Smit, P. Cuijpers, J. Oostenbrink, N. Batelaan, R. de Graaf, A. Beekman, Costs of nine common mental disorders: Implications for curative and preventive psychiatry. *J. Ment. Health Policy Econ.* **9**, 193–200 (2006).
251. R. C. Kessler, S. Heeringa, M. D. Lakoma, M. Petukhova, A. E. Rupp, M. Schoenbaum, P. S. Wang, A. M. Zaslavsky, Individual and societal effects of mental disorders on earnings in the United States: Results from the national comorbidity survey replication. *Am. J. Psychiatry* **165**, 703–711 (2008).
252. E. Shirmeshan, J. Bailey, G. Relyea, B. E. Franklin, D. K. Solomon, L. M. Brown, Incremental direct medical expenditures associated with anxiety disorders for the U.S. adult population: Evidence from the Medical Expenditure Panel Survey. *J. Anxiety Disord.* **27**, 720–727 (2013).
253. M. Sado, S. Takechi, A. Inagaki, D. Fujisawa, A. Koreki, M. Mimura, K. Yoshimura, Cost of anxiety disorders in Japan in 2008: A prevalence-based approach. *BMC Psychiatry* **13**, 338 (2013).
254. M. T. Nguyen, W. Y. Chan, C. Keeler, The association between self-rated mental health status and total health care expenditure: A cross-sectional analysis of a nationally representative sample. *Medicine* **94**, e1410 (2015).
255. J. Dams, H. H. König, F. Bleibler, J. Hoyer, J. Wiltink, M. E. Beutel, S. Salzer, S. Herpertz, U. Willutzki, B. Strauß, E. Leibing, F. Leichsenring, A. Konnopka, Excess costs of social anxiety disorder in Germany. *J. Affect. Disord.* **213**, 23–29 (2017).
256. D. Chisholm, K. Sweeny, P. Sheehan, B. Rasmussen, F. Smit, P. Cuijpers, S. Saxena, Scaling-up treatment of depression and anxiety: A global return on investment analysis. *Lancet Psychiatry* **3**, 415–424 (2016).
257. C. S. Burckhardt, K. L. Anderson, The quality of life scale (QOLS): Reliability, validity, and utilization. *Health Qual. Life Outcomes* **1**, 60 (2003).
258. R. C. Buckley, P. Brough, Economic value of parks via human mental health: An analytical framework. *Front. Ecol. Evol.* **5**, 16 (2017).
259. Central Puget Sound Open Space Assessment Tool (2017); <https://web.tplgis.org/OSAT/>.
260. V. Shandas, J. Voelkel, M. Rao, L. George, Integrating high-resolution datasets to target mitigation efforts for improving air quality and public health in urban neighborhoods. *Int. J. Environ. Res. Public Health* **13**, 790 (2016).
261. J. Voelkel, V. Shandas, B. Haggerty, Developing high-resolution descriptions of urban heat islands: A public health imperative. *Prev. Chronic Dis.* **13**, e129 (2016).
262. T. Briceno, J. Mojica, *Statewide Land Acquisition and New Park Development Strategy* (Earth Economics, 2016).
263. R. Rosenberger, T. Bergerson, J. D. Kline, Macro-linkages between health and outdoor recreation: The role of parks and recreation providers. *J. Park Recreation Admin.* **27**, 8–20 (2009).
264. R. Rosenberger, *Oregon's Statewide Comprehensive Outdoor Recreation Plan (SCORP): Health and Recreation Linkages in Oregon: Physical Activity, Overweight, and Obesity* (2007).
265. City of Seattle, Equity and environment agenda (2016); <http://www.seattle.gov/Documents/Departments/OSE/SeattleEquityAgenda.pdf>.
266. A. C. K. Lee, H. C. Jordan, J. Horsley, Value of urban green spaces in promoting healthy living and wellbeing: Prospects for planning. *Risk Manag. Healthc. Policy* **8**, 131–137 (2015).

267. I. Alcock, M. P. White, B. W. Wheeler, L. E. Fleming, M. H. Depledge, Longitudinal effects on mental health of moving to greener and less green urban areas. *Environ. Sci. Technol.* **48**, 1247–1255 (2014).
268. E. M. Bijnens, T. S. Nawrot, R. J. Loos, M. Gielen, R. Vlietinck, C. Derom, M. P. Zeegers, Blood pressure in young adulthood and residential greenness in the early-life environment of twins. *Environ. Health* **16**, 53 (2017).
269. Q. Li, Effect of forest bathing trips on human immune function. *Environ. Health Prevent. Med.* **15**, 9–17 (2010).
270. E. Silveirinha de Oliveira, P. Aspinall, A. Briggs, C. Cummins, A. H. Leyland, R. Mitchell, J. Roe, C. Ward Thompson, How effective is the Forestry Commission Scotland's woodland improvement programme—'Woods In and Around Towns' (WIAT)—At improving psychological well-being in deprived communities? A quasi-experimental study. *BMJ Open* **3**, e003648 (2013).
271. E. Dahlkvist, T. Hartig, A. Nilsson, H. Högberg, K. Skovdahl, M. Engström, Garden greenery and the health of older people in residential care facilities: A multi-level cross-sectional study. *J. Adv. Nurs.* **72**, 2065–2076 (2016).
272. E. von Lindern, T. Hartig, P. Lercher, Traffic-related exposures, constrained restoration, and health in the residential context. *Health Place* **39**, 92–100 (2016).
273. M. Kuo, How might contact with nature promote human health? Promising mechanisms and a possible central pathway. *Front. Psychol.* **6**, 1093 (2015).

**Acknowledgments:** This paper represents a consensus of diverse coauthors who developed the ideas and text together as part of a formal working group supported by the Natural Capital Project, with funding from the Marianne and Marcus Wallenberg Foundation and John Miller. We thank G. Young for superb research assistance. For

stimulating discussions, we are grateful to members of the University of Washington EarthLab, the School of Environmental and Forest Sciences at the University of Washington, the Stanford Center for Conservation Biology, the Stanford Psychophysiology Laboratory, and the Emmett Interdisciplinary Program in Environment and Resources (E-IPER).

**Funding:** We appreciate funding to support G.N.B. from the Doug Walker Endowed Professorship, Craig McKibben and Sarah Merner, John Miller, the Marianne and Marcus Wallenberg Foundation, the Winslow Foundation, the George Rudolf Fellowship Fund, the Victoria and David Rogers Fund, and the Mr. & Mrs. Dean A. McGee Fund. **Author contributions:** G.N.B., C.B.A., M.G.B., B.C., S.d.V., J.F., C.F., H.F., J.J.G., T.H., P.H.K., M.K., J.J.L., P.S.L., T.L., A.M.-L., R.M., Z.O., J.R., L.S., J.R.S., M.v.d.B., B.W.W., M.P.W., H.Z., and G.C.D. wrote the paper. **Competing interests:** The authors declare that they have no competing interests. **Data and materials availability:** All data needed to evaluate the conclusions in the paper are present in the paper and/or the Supplementary Materials. Additional data related to this paper may be requested from the authors.

Submitted 20 February 2019

Accepted 20 June 2019

Published 24 July 2019

10.1126/sciadv.aax0903

**Citation:** G. N. Bratman, C. B. Anderson, M. G. Berman, B. Cochran, S. de Vries, J. Flanders, C. Folke, H. Frumkin, J. J. Gross, T. Hartig, P. H. Kahn Jr., M. Kuo, J. J. Lawler, P. S. Levin, T. Lindahl, A. Meyer-Lindenberg, R. Mitchell, Z. Ouyang, J. Roe, L. Scarlett, J. R. Smith, M. van den Bosch, B. W. Wheeler, M. P. White, H. Zheng, G. C. Daily, Nature and mental health: An ecosystem service perspective. *Sci. Adv.* **5**, eaax0903 (2019).



## Nature and mental health: An ecosystem service perspective

Gregory N. Bratman, Christopher B. Anderson, Marc G. Berman, Bobby Cochran, Sierp de Vries, Jon Flanders, Carl Folke, Howard Frumkin, James J. Gross, Terry Hartig, Peter H. Kahn, Jr., Ming Kuo, Joshua J. Lawler, Phillip S. Levin, Therese Lindahl, Andreas Meyer-Lindenberg, Richard Mitchell, Zhiyun Ouyang, Jenny Roe, Lynn Scarlett, Jeffrey R. Smith, Matilda van den Bosch, Benedict W. Wheeler, Mathew P. White, Hua Zheng and Gretchen C. Daily

*Sci Adv* **5** (7), eaax0903.  
DOI: 10.1126/sciadv.aax0903

### ARTICLE TOOLS

<http://advances.sciencemag.org/content/5/7/eaax0903>

### SUPPLEMENTARY MATERIALS

<http://advances.sciencemag.org/content/suppl/2019/07/22/5.7.eaax0903.DC1>

### REFERENCES

This article cites 242 articles, 18 of which you can access for free  
<http://advances.sciencemag.org/content/5/7/eaax0903#BIBL>

### PERMISSIONS

<http://www.sciencemag.org/help/reprints-and-permissions>

Use of this article is subject to the [Terms of Service](#)

*Science Advances* (ISSN 2375-2548) is published by the American Association for the Advancement of Science, 1200 New York Avenue NW, Washington, DC 20005. The title *Science Advances* is a registered trademark of AAAS.

Copyright © 2019 The Authors, some rights reserved; exclusive licensee American Association for the Advancement of Science. No claim to original U.S. Government Works. Distributed under a Creative Commons Attribution NonCommercial License 4.0 (CC BY-NC).