SOCIAL SCIENCES

Nature and mental health: An ecosystem service perspective

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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*).

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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,

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 progressively 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 bio- 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

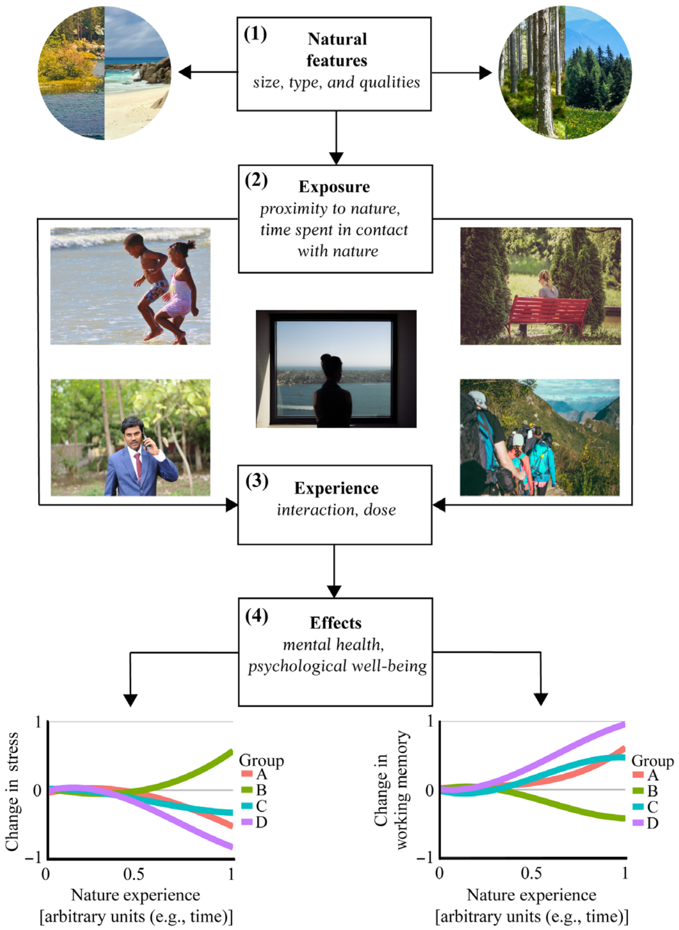

Fig. 1. A conceptual model for mental health as an ecosystem service. (1) Natural features include the characteristics (size, type, and qualities such as configuration) of the nature under consideration. (2) Exposure is estimated through methods that take proximity, likelihood, and duration of nature 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. Ekkel 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.

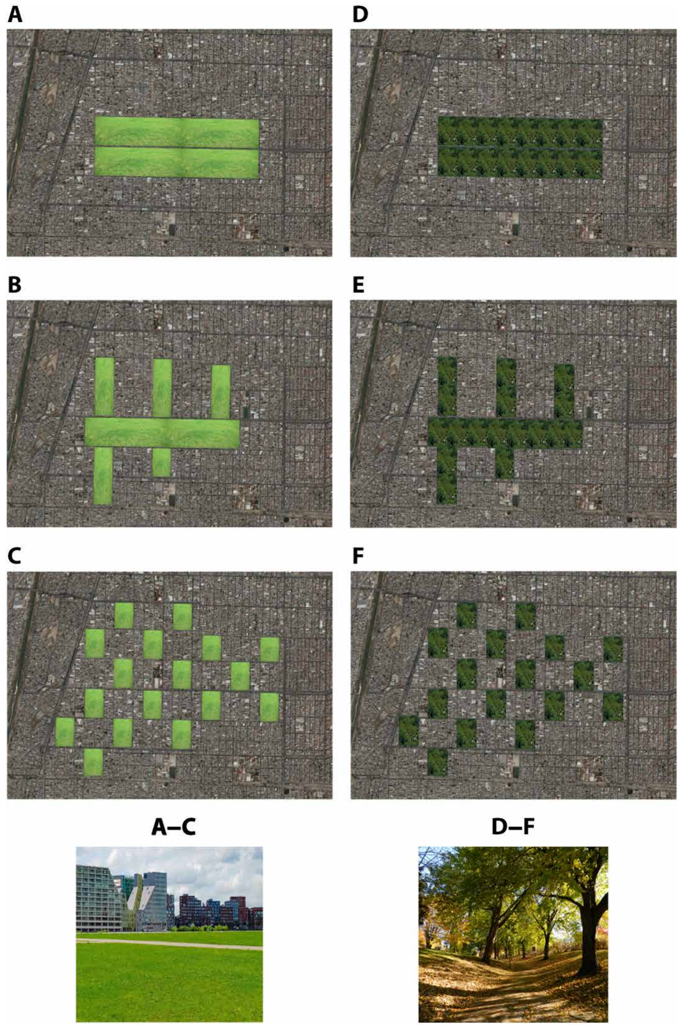

Fig. 2. Configuration and composition of urban green space. Along with other factors, spatial configuration and composition should be considered when estimating nature exposure. Different shades of green here represent different types of nature [e.g., clusters of open lawns (**A** to **C**) versus trees (**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.

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. 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 environmental 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.

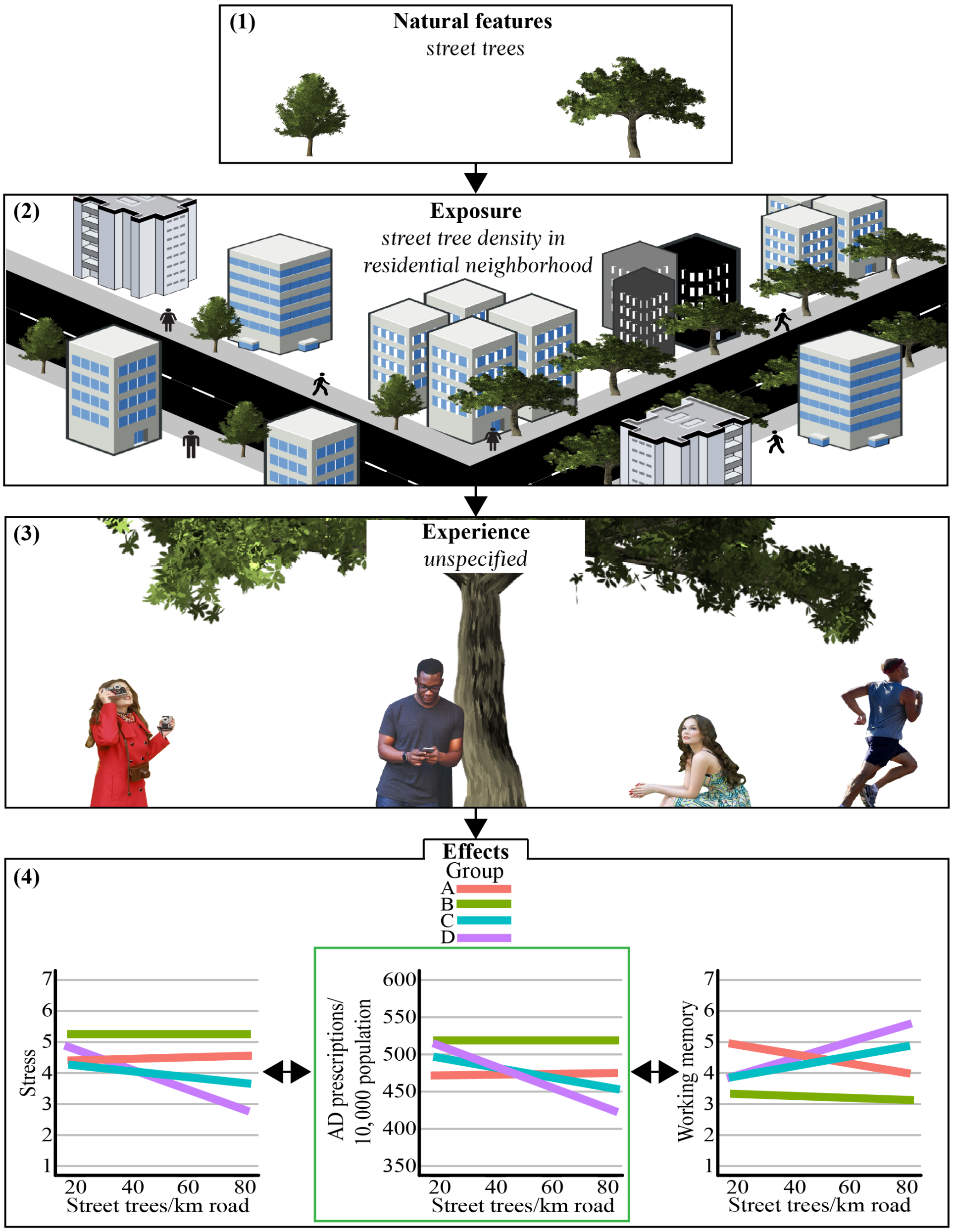

Fig. 3. A hypothetical application of the conceptual model using a case study for which antidepressant prescription is the outcome. Information is gathered for each of the three steps. (1) Natural features in this case are street trees (other characteristics unspecified, including spatial configuration). (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 workthrough 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*)

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