Quantifying Nature: Introducing NatureScore™ and NatureDose™ as Health Analysis and Promotion Tools

Matthew H. E. M. Browning, PhD[1,2], **Jared R. Hanley, BA**[2], **Christopher R. Bailey, BS**[2], **Timothy Beatley, PhD**[3], **Samantha Gailey, PhD**[4,5], **J. Aaron Hipp, PhD**[6], **Lincoln R. Larson, PhD**[6], **Peter James, PhD**[7], **Viniece Jennings, PhD**[8], **Marcia Pescador Jimenez, PhD**[9], **Peter H. Kahn Jr., PhD**[10], **Dongying Li, PhD**[11], **Aaron Reuben, PhD**[12], **Alessandro Rigolon, PhD**[13], **Naomi A. Sachs, PhD**[14], **Amber L. Pearson, PhD**[15], **Christopher T. Minson, PhD**[2,16]

[1]Department of Parks, Recreation and Tourism Management, Clemson University, Clemson, SC, USA

[2]NatureQuantTM, Inc., Eugene, OR, USA

[3]School of Architecture, University of Virginia, Charlottesville, VA, USA

[4]Department of Forestry, Michigan State University, East Lansing, MI, USA

[5]Space, Health and Community Lab, Charles Stewart Mott Department of Public Health, Michigan State University, East Lansing, MI, USA

[6]Department of Parks, Recreation & Tourism Management, North Carolina State University, Raleigh, NC, USA

[7]Department of Environmental Health, Harvard T. H. Chan School of Public Health, Boston, MA, USA

[8]School of the Environment, Florida Agricultural and Mechanical University, Tallahassee, FL, USA

[9]Department of Epidemiology, Boston University, Boston, MA, USA

[10]Department of Psychology & School of Environmental and Forest Sciences, University of Washington, Seattle, WA, USA

[11]Department of Landscape Architecture and Urban Planning, Texas A&M University, College Station, TX, USA

[12]Department of Psychology & Neuroscience, Duke University, Durham, NC, USA

[13]Department of City & Metropolitan Planning, The University of Utah, Salt Lake City, UT, USA

[14]Department of Plant Science and Landscape Architecture, University of Maryland, College Park, MD, USA

Corresponding Author: Christopher T. Minson, NatureQuantTM, Inc., Eugene, OR, USA; Department of Human Physiology, University of Oregon, Eugene, OR, USA. minson@uoregon.edu; chris.minson@naturequant.com.

[15]Charles Stewart Mott Department of Public Health, Michigan State University, East Lansing, MI, USA

[16]Department of Human Physiology, University of Oregon, Eugene, OR, USA

The Value of Nature Exposure in the 21st Century

Humanity is undergoing a monumental shift. People have rapidly moved from a largely natural, outdoor existence to life in built, urban settings. Most places where people live and work differ dramatically from the ones we occupied for 99.9% of human history, and our current surroundings often physically separate us from the natural world. Most people —over half globally and approximately 4 in 5 in the United States—now live in urban areas,[1] where nearby nature exposure tends to be limited[2] and unequally distributed across socioeconomic and racial/ethnic subgroups.[3–6] Adults in higher-income countries spend 80%–90% of their lives sedentary and indoors,[7–9] with 6 to 8 hours or more spent each day looking at screens.[10–12] The same is increasingly true for our developing youth,[10,13,14] who may experience poorer health across their life span as a result.[15]

Over the last 30 years, physicians, scientists, and journalists have come to suspect that we are experiencing a "nature deficit disorder," or "extinction of experience".[16–22] With the loss of direct exposure to nature has also come diminished knowledge of where food comes from, an inability to recognize plants and animals, fewer opportunities to experience awe (being in the presence of something vast that transcends current understandings of the world), and a failure to develop positive emotions and empathy toward other people and the non-human world.[23–25]

In response to growing concerns about this radical shift, scientists worldwide have studied how nature exposure is associated with human health.[26–31] The links between declining nature exposure and increasing depression, anxiety, heart disease, and premature mortality are increasingly clear.[26,32] A large and growing body of scientific literature demonstrates that exposure to nature, broadly encompassing green spaces, trees, parks, water bodies, deserts, wilderness areas, wildlife, and more,[30,33] is associated with measurable and meaningful benefits to dozens of facets of psychological and physical health.[31,33–35] These benefits can follow from nature exposure in a variety of forms, from passively viewing nature from a park bench to walking along a tree-lined street or practicing shinrin-yoku ("forest bathing")[36] in an urban forest. At a population level, the presence of nature has also been linked to important societal benefits, such as higher property values,[37] lower healthcare expenses,[38,39] lower levels of air pollution, noise, and heat,[40–43] as well as lower crime rates,[44,45] enhanced social mobility,[46] more cohesive communities,[47–50] and resilience to public health crises, such as the COVID-19 pandemic.[50,51] These beneficial associations are believed to result from natural areas mitigating environmental hazards, restoring cognitive capacity, reducing stress reactivity, facilitating interactions with commensurate microbiota, and promoting healthy behaviors, such as physical activity and social interaction.[30,34,52,53]

Like exercise, sleep, and a healthy diet,[54] nature exposure may well be a necessary health behavior to promote longevity, prevent disease, and enhance wellbeing.[55–57] "Nature

prescribing" by healthcare providers, a growing movement, can serve as a tool for health promotion with minimal cost, side effects, equipment needs, or training requirements. Few medications or existing interventions can match these qualities. For instance, the American Heart Association's "Life's Essential 8" asserts that the following can help achieve an "ideal" cardiovascular health: a healthy diet, 150 minutes of moderate exercise or 75 minutes of vigorous exercise per week, not smoking or vaping, sleeping 7 to 9 hours each night, maintaining a healthy body mass index, and regularly checking and maintaining cholesterol, fasting blood sugar, and blood pressure levels.[54] Nature exposure might be comparable to several of these recommendations in terms of potential health benefits and come with fewer barriers to starting and maintaining a regular practice.

Assessing and Promoting Nature Exposure With Technology

Utilizing nature to promote health requires convenient and accurate technologies to quantify peoples' daily exposure levels. Despite growing evidence of the benefits of nature exposure for our increasingly indoor and sedentary society, health practitioners have generally been slow to embrace the concept of nature-based health promotion. One reason is the lack of consensus around a standard measure of nature exposure.[56,58] How do we know which patients lack regular nature exposure, how much "dose" to prescribe, or how to measure prescription adherence? There are many existing methods to measure nature exposure, but these require expertise, equipment, or underlying data unavailable to most patients and practitioners in the healthcare sector.[59] Reliable information is needed on both the quantity (frequency and duration) and quality (e.g., levels of "greenness," "restorativeness," or "naturalness") of exposure.[60–63] These measurement challenges make incorporating nature exposure into healthcare practice difficult.

Advancements in geospatial datasets, exposure assessment, tracking methodology, and big data/machine learning techniques provide opportunities to meet the unmet nature-exposure measurement need. NatureQuant™, a new research and technology institution, was formed with this goal in mind. It recently created 2 technologies that may help overcome existing barriers in quantifying nature exposure and, in turn, expand its use for health promotion.[64]

The first technology is the NatureScore™ dataset and tool, which summarizes the environmental conditions at a given location to generate an overall "NatureScore" value, discussed below. The second technology is the "NatureDose" mobile app, which references NatureScore™ values as an individual moves through time and space to generate an overall metric of nature exposure over time (Figure 1). These technologies are beginning to help researchers refine our understanding of the benefits of nature exposure and catalyze the use of nature as a health promotion tool.[65,66]

NatureScore™: Quantifying Nature Based on Human Health Associations

NatureScore™ is a patent-pending dataset and tool that estimates the amount and quality of nature and associated environmental conditions at any location (Figure 2) in the United States and Canada, with expansion to Europe and Australia in the near future. For any given location or spatial unit (i.e., census block or tract), NatureQuant analyzed approximately 30 data sets and processed information with up to a 10-m^2 granularity, ultimately returning

NatureScore[TM] values ranging from 0 (nature-deprived) to 100 (nature-rich) (Figure 3). These datasets cover a wide range of types of environmental determinants of health, from satellite images of vegetation to land cover and land use classifications, park areas and features, tree canopy cover estimates, air pollution, noise levels, artificial light at night values, buildings, roads, impervious surfaces, and aerial and street view images. Each dataset is weighted and summed to create an overall NatureScore[TM] value based on the results of machine learning models with environmental exposures as input features and geotagged health outcomes (i.e., mortality rates) as output features.

NatureScore[TM] is not static and rerun with regularly updated input datasets to account for changes in land cover and use (i.e., urban development or natural disasters) and output variables (i.e., incidence of various diseases and illnesses). The underlying environmental and health datasets are expected to be refined and expanded over time to allow for improved accuracy and coverage. Because of this process, NatureScore[TM] does not have a fixed algorithm. For example, in its current iteration, NatureScore[TM] examines 2010–2015 life expectancy estimates in U.S. Census tracts from the U.S. Small-Area Life Expectancy Project (USALEEP)[67] alongside Sentinel-2A-derived cloud and water-corrected NDVI values at 10-m^2 resolution; the European Space Agency (ESA) WorldCover land cover product at 10-m^2 resolution;[68] park polygons from various governmental geospatial datasets available under the Open Data Commons Open Database License; and Microsoft Maps[69] data from 2022 for nearly 130,000,000 computer-generated building footprints, among other datasets. Sixty percent of the contribution for a longevity-optimized NatureScore[TM] might be from vegetation indices. Another 20% might be derived from other nature-based metrics (e.g., visible greenery in street view images, park cover, blue space cover, and nature-based land covers). The remaining 20% might be derived from human modifications on the landscape (e.g., buildings, roads, and impervious surfaces). In contrast, a mental health-optimized NatureScore[TM] might have a lower weighting for vegetation indices and higher weighting for datasets with other natural and built features.

NatureDose[TM]: Quantifying Nature Exposure With a Passive Smartphone App

NatureDose[TM] is a mobile smartphone application that passively monitors how many minutes a person spends indoors, outdoors, and outdoors in nature (Figure 4). The app uses the smartphone's sensors, geolocation from satellite-derived geographic position system (GPS) coordinates, and NatureScore[TM] dataset to determine where users are located, whether inside or outside, and how much nature is within a 1-km buffer.

When a user is determined to be outdoors and in a designated natural area (i.e., park, wilderness, or on a river), the app assigns full nature exp exposure time credit to the user. When a user is outdoors and not in a designated natural area, the app assigns only partial nature exposure time credit. Additionally, based on the accelerometer and other smartphone sensors, the app determines when users are in a car or other motorized vehicle. No NatureDose[TM] time credit is given when these vehicles are in motion. Other forms of transportation, like walking or bicycling, earn NatureDose[TM] credit. All time in nature (outside of motor vehicles) is counted toward the weekly total, including passive forms (i.e., sitting on a park bench) and active forms (e.g., walking along a tree-lined street or manual

labor outdoors). NatureDose also provides an integration for Strava, a popular geospatial exercise-tracking app, to show users the average NatureScore™ value for their recorded activity and the number of minutes earned to their NatureDose™ weekly score.

NatureDose™ also allows users to set a weekly goal (in minutes) for time spent outdoors in nature and then tracks the users' progress toward the goal. Default options are 30, 60, and 120 min/wk. (These values are derived from research on associations between nature dose levels and general health,[70] depression and blood pressure,[71] stress recovery,[72] and other forms of psychological and physiological markers of well-being.[73]) The app can send push notifications when the goal is met and includes language on the health benefits of nature to encourage going outdoors. The complete terms of use and uses of data are available online (https://www.naturequant.com/terms-of-use/).

The app provides several opportunities for clinicians, researchers, and policymakers. For clinicians, the app allows users and prescribers to set and monitor goals for time in nature each week. The app also allows baseline measures of time in nature before a "nature prescription."

For researchers, the app allows for the evaluation of baseline nature exposure levels before and after nature-based interventions and complements other common ways to estimate nature exposure for study members, such as greenness around homes, schools, and offices.[58,59] The app determines how user reports of time in nature and perceived nature deficiencies[74] correspond to objective measures of these phenomena. The app's data on nature exposure can be richer, more nuanced, and personalized than other common techniques, such as estimating exposure around the home. Thus, the app's data can be linked to measures of objective and perceived health, enabling researchers to understand further the relationships linking nature and health. Since the app provides information on time spent outdoors in designated natural areas vs outdoors in nature-deprived areas, researchers can understand how the richness of nature enhances other health-promoting behaviors. For example, physical activity in nature-rich areas may contribute more to perceived or objective health than indoors or outdoors with poor environmental conditions (i.e., low NatureScore™ values).

The app can also advance our understanding of disparities in high-quality parks and vegetation by socioeconomic status[3] or historic redlining[4] through evidence of disparities in nature visitation rates across socioeconomic status. Understanding nature-visit disparities may enable targeted nature-based health interventions where natural spaces are accessible but usage amongst disadvantaged populations is low. This understanding can also guide decision-making around where to allocate resources to create new parks or improve or expand existing parks based on residents' nature doses.

To date, the app has been used in completed health studies in Oregon[66] and South Carolina[65] with numerous other studies underway. Studies have found that NatureDose™-measured nature exposure was associated with lowered stress levels[66] and improved positive mood states,[65] as reported in survey responses among college students. Trials where healthcare providers are "prescribing" time outdoors in nature and requesting participants monitor

exposure using the app are being conducted in Vermont,[75] Texas, and Oregon. Researchers and clinicians are also pursuing funding for studies to use the app and NatureScore™ technology to monitor participants' environmental exposures and health outcomes.

Limitations and Future Directions

NatureScore™ and NatureDose™ have several limitations and opportunities for improvement that should be considered when using them to quantify nature. While representing nature with a single metric makes NatureScore™ easy to use and interpret, this reductionist approach raises several questions. Singular metrics for complex topics like nature exposure or economic performance (i.e., gross domestic product [GDP]) are prone to miss important parameters that should be considered.[76,77] Over-reliance on these metrics may lead to inadequately informed decisions in policy and practice.[76] Relatedly, the underlying data and algorithms in NatureScore™ are unlikely to fully represent the contextual and individual factors that determine whether a specific person benefits from nature at a specific location. NatureScore™ input datasets are correlated with health outcomes at nationwide scales. Local variations in the types of nature most strongly linked to health may vary. For instance, elements in deserts like sand or rock have less-established benefits for large populations[33] and are weighted lower in the dataset. For desert residents, however, these elements may be just as health-promoting as green vegetation, assuming they are perceived as non-threatening.[78–80] The literature is not yet clear on the nonvisual elements of nature that may benefit human health, such as phytoncides (volatile compounds produced by certain trees), smells, natural sounds such as bird songs, and tactile stimulation.[81] Most data used to calculate NatureScore™ values are based on remote sensing, street view imagery, and other visual representations of nature. Aspects associated with other sensory inputs, such as biodiversity for birdsong or forest composition for phytoncides, are not directly measured. Additionally complicating the potential health benefits of myriad types of nature is the potential for individual-level moderators, such as feelings of nature connectedness, childhood experiences, and comfort with the diurnal and seasonal variations in climate and vegetative color and features where an individual lives.

NatureQuant™ technologies also have not undergone comprehensive validation studies with existing nature exposure metrics. One exception is a nationwide, tract-level comparison of NatureScore™ with 3 commonly used nature exposure metrics.[6] Both NatureScore™ and NDVI showed patterns of more nature in tracts with less poverty, lower shares of non-Hispanic Whites, and higher incomes. However, sociodemographic patterns for blue space cover and park cover differed dramatically from NatureScore™. There is an urgent need for studies with the general public to quantify how much "nature" is around where they live, work, learn, and travel and compare these assessments with NatureScore™ values. These data would allow a better understanding of what components of nature that NatureScore™ may represent most strongly. Another opportunity to validate NatureScore™ would be to compare its values with expert assessments of perceived neighborhood restorativeness, as done with the normalized difference vegetation index (NDVI).[61] However, as discussed above, NatureScore™ is a dynamic system with updates to its dataset algorithms based on the available data and the health outcome of greatest interest. Validation studies will be

needed on NatureScore™ over time when variations on the product for specific use cases become available.

Similarly, the NatureDose™ app has not been compared to other ways of measuring dynamic exposure, such as GPS tracking, accelerometers, automated cameras, and self-report data. Its inside vs outside calculation is vulnerable to exposure misclassification since it partially relies on building footprint spatial data that can become outdated in areas of development and growth. In these circumstances, users may earn nature exposure minutes when they are outside but in areas that no longer have natural elements, or earn nature exposure minutes when they are indoors. Meanwhile, nature exposure minutes cannot be earned without the user carrying a smartphone, which is not always feasible or desired during nature-based activities. Limitations to smartphone battery life and data also extend to the app.

Technology and Nature Working Together for Health Promotion

Nature and technology are often opposing forces.[82–86] In our modern "always connected" society, however, technology may now be useful for helping us re-engage with nature. The NatureScore™ and NatureDose™ tools have been created to help assist in that effort by attempting to quantify nature in a reliable, scalable, and accessible way. We hope that these and other similar efforts help us chart a path toward a healthier, more nature-rich future.

Acknowledgments

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Figure 1.
New tools to quantify nature at any location in the United States (NatureScore™, left panel) and an individual's daily or weekly exposure to nature (NatureDose™, right panel). The app provides NatureScore™ values to users within a 1-km buffer, although values can be calculated at smaller distances or averaged across spatial units (i.e., census tracts).
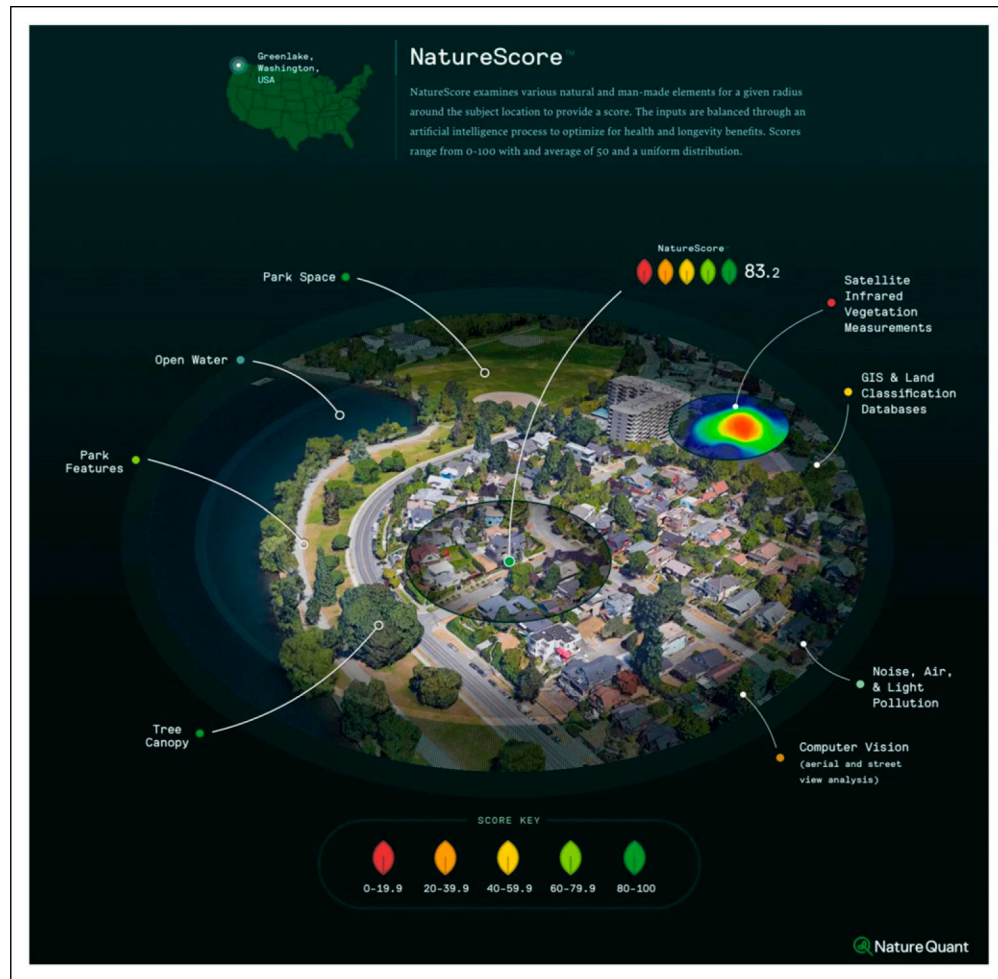
Figure 2.
NatureScore™ attempts to quantify the amount and quality of nature and the environmental conditions at any location by combining over 30 environmental and human-health datasets with machine learning.
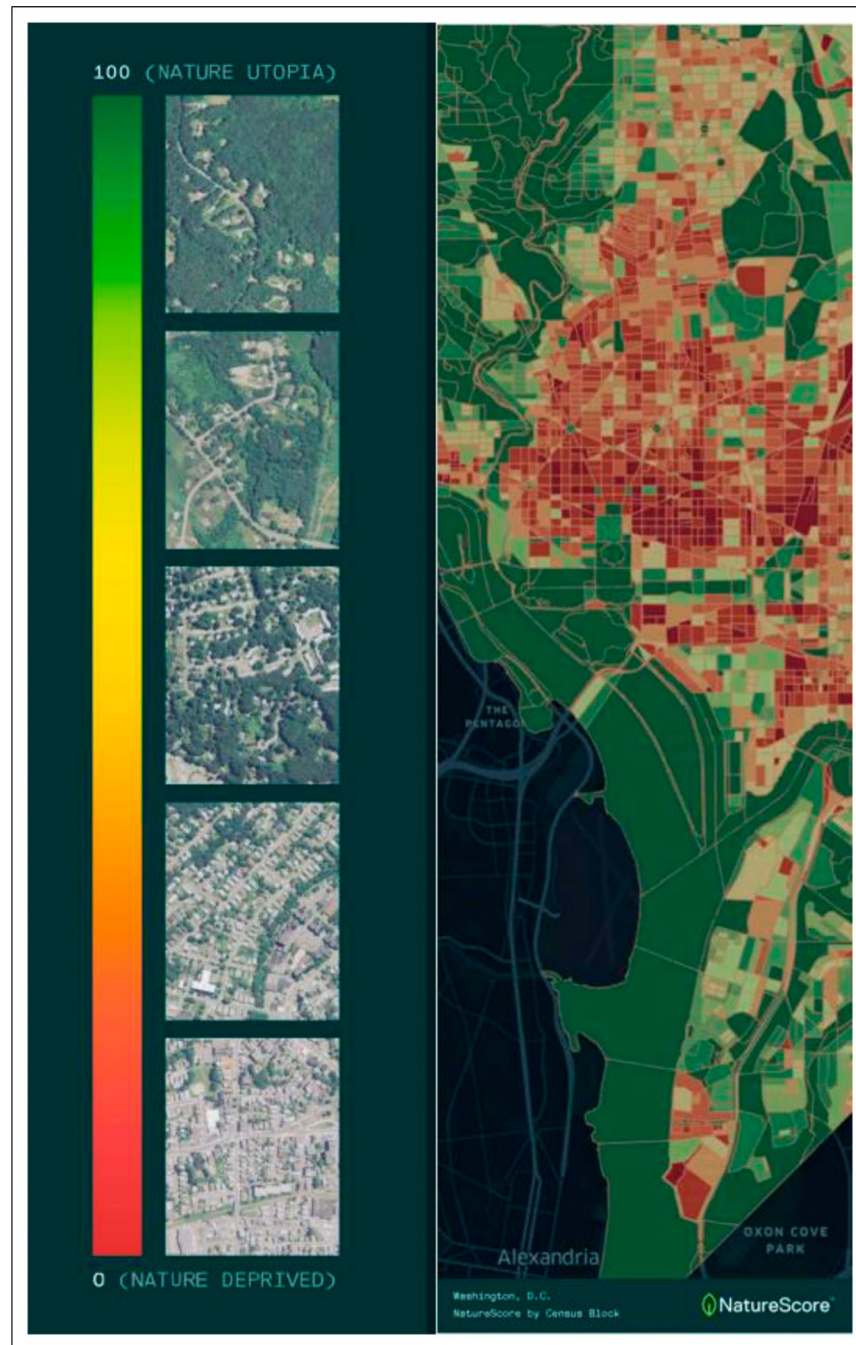
Figure 3.

NatureScore™ values range from 0 (nature-deprived) to 100 (nature-rich) and can be calculated within buffers at any location (i.e., 300-m around homes) or averaged across spatial units (i.e., census tract).
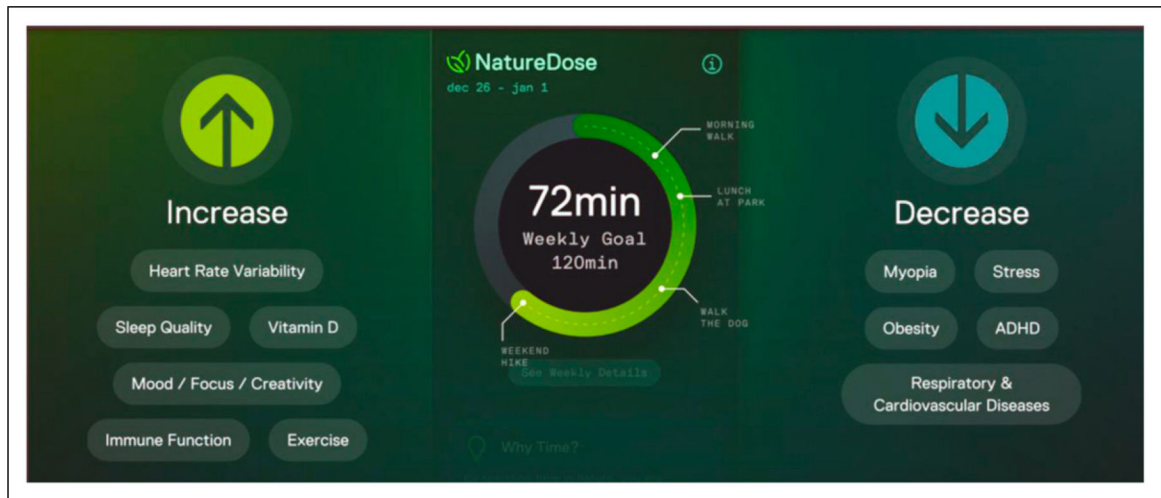
Figure 4.

Screenshots from the NatureDose™ smartphone app, which attempts to monitor the number of minutes per week outdoors in nature (center panel) as well as indoors and outdoors (not in nature); the app also reports the potential health benefits of nature exposure to its users (left and right panels).