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Review

Beyond "bluespace" and "greenspace": A narrative review of possible health benefits from exposure to other natural landscapes

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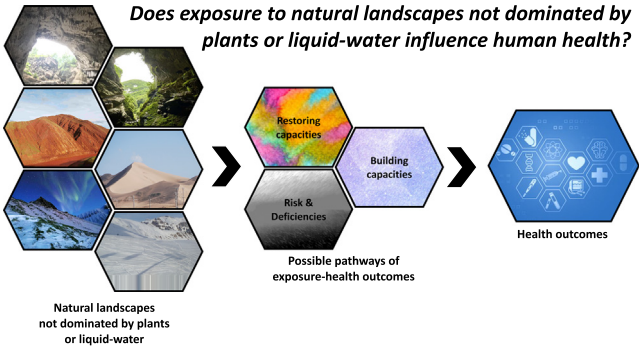
HIGHLIGHTS

- Greenspace and bluespace research is booming, but nature is not always green or blue.
- Color-coding natural landscapes could provide confusing and misleading descriptions.
- Natural landscapes are largely composed of plants, water, and rocks/minerals.
- Caves, deserts, and landscapes with ice/snow may pose health benefits and risks.
- More high-quality research on the broad array of natural landscapes is needed.

GRAPHICAL ABSTRACT



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ABSTRACT

Numerous studies have highlighted the physical and mental health benefits of contact with nature, typically in landscapes characterized by plants (i.e., "greenspace") and water (i.e., "bluespace"). However, natural landscapes are not always green or blue, and the effects of other landscapes are worth attention. This narrative review attempts to overcome this limitation of past research.

Rather than focusing on colors, we propose that natural landscapes are composed of at least one of three components: (1) plants (e.g., trees, flowering plants, grasses, sedges, mosses, ferns, and algae), (2) water (e.g., rivers, canals, lakes, and oceans), and/or (3) rocks and minerals, including soil. Landscapes not dominated by plants or liquid-state water include those with abundant solid-state water (e.g., polar spaces) and rocks or minerals (e.g., deserts and caves). Possible health benefits of solid-state water or rock/mineral dominated landscapes include both shorter-term (e.g., viewing images) and longer-term (e.g., living in these landscapes) exposure durations. Reported benefits span improved emotional and mental states and medical treatment resources for respiratory conditions and allergies. Mechanisms underlying the health benefits of exposure consist of commonly discussed theories in the "greenspace" and

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"bluespace" literature (i.e., instoration and restoration) as well as less discussed pathways in that literature (i.e., post-traumatic growth, self-determination, supportive environment theory, and place attachment).
This is the first review to draw attention to the potential salutogenic value of natural landscapes beyond "greenspace" and "bluespace." It is also among the first to highlight the limitations and confusion that result from classifying natural landscapes using color. Since the extant literature on natural landscapes - beyond those with abundant plants or liquid-state water - is limited in regard to quantity and quality, additional research is needed to understand their restorative potential and therapeutic possibilities.

Contents

1. Introduction

The health benefits of contact with nature are widely recognized across human cultures. For example, 天人合一 (the harmony between humanity and nature) is a core idea in Chinese culture (Lai et al., 2022). Shinrin-yoku, or forest bathing, is an increasingly popular form of nature therapy used to promote physiological and psychological health in many parts of the world (Hansen et al., 2017). American poet Ralph Waldo Emerson described "the lover of nature is he whose inward and outward senses are still truly adjusted to each other; who has retained the spirit of infancy even into the era of manhood" (Emerson, 1903, p. 9), inspiring a fascination with nature-based health promotion in Western countries (Larson and Hipp, 2022). Modern empirical research supports a strong link between nature and human health, but it also highlights potentially variable effects across diverse types of natural landscapes via different mechanisms (Hartig et al., 2014).

The health-promoting potential of nature exposure is often assumed to be driven by our genes (Kaplan and Kaplan, 1989; Wilson, 1986; Ulrich, 1983), an adaptive trait paralleled with biophilia, meaning humans' inherent affinity for other forms of life (Kellert and Wilson, 1993). Most of human evolutionary history has occurred in natural surroundings (Joye and van den Berg, 2011; Moura et al., 2017). Not until recent centuries, following the industrial revolution, have a majority of humans lived outside of and apart from nature-rich environments (Turner et al., 2004; Vlahov and Galea, 2002). Therefore, while humans' direct connection with natural environments may be diminishing, our evolutionary-driven connections with natural landscapes and resulting health impacts are likely to remain viable today (Laland and Brown, 2006; Robinson and Breed, 2020).

Scholars have proposed the "therapeutic landscape" concept to explain why certain places contribute to health promotion and treatment. With roots in cultural ecology, structuralism, and humanism (Gesler, 1992; Williams, 1998), this concept spans multiple dimensions of wellbeing including material/physical, social, and spiritual (Bell et al., 2018). The physical environment of therapeutic landscapes includes natural and human-made environments (Gesler, 2018). Natural landscapes characterized by plants and liquid water have received perhaps the most attention (Bell et al., 2018; Bell et al., 2017). This focus is not surprising, as these two elements are common components in many natural landscapes inhabited by people. They also supply basic resources for survival (Reid et al., 2005). Water is a fundamental part of life, and plants provide many ecological services, including the production of organic matter for food and oxygen for breathing (Carpenter et al., 2009). For these reasons, much research has been conducted on the health benefits of natural settings rich in these ecosystem services (Bratman et al., 2019; Zhang et al., 2020).

Studies on the health benefits of plant and liquid water-dominated landscapes often use color schemes to code landscapes with these components (Twohig-Bennett and Jones, 2018; White et al., 2020). In this context, "greenspace" refers to landscapes rich with plants (e.g., trees, flowering plants, grasses, sedges mosses, ferns, and algae), and "bluespace" refers to landscapes with open water (e.g., canals, rivers, lakes, oceans). However, nature is not limited to plants or open water, and this binary characterization omits key components of potentially therapeutic natural landscapes.

Emerging concepts such as "white space" (e.g., snow-covered landscapes; Brooke and Williams, 2021; Finlay, 2018; Korpela et al., 2014; Olwig, 2005; Yli-Panula et al., 2022), "brown space" (e.g., deserts; Nazif-Munoz et al., 2020; Olvera-Alvarez et al., 2021; Yin et al., 2022), and "red nature" (e.g., volcanoes; Kotera et al., 2021) bring more types of landscapes into scholarly discourse. Human perceptions of landscapes are undoubtedly shaped by sight and visual attributes, such as color, that contribute to experiences related to place (Bell, 2012; Lengen, 2015; Zhang et al., 2022). Nevertheless, there are limitations to the use of color-coding to describe natural landscapes. Non-visual sensory perceptions such as sound may have a strong influence on the health benefits associated with nature (Buxton et al., 2021). Additionally, color may not clearly indicate landscapes that are alien to most people. For example, general readers may not associate "red nature" with volcanoes without extra description (Kotera et al., 2021). To add more complexity, plants and water change color with time, season, and place, which might limit the relevance of the classic "green" and "blue" coding (Zhou et al., 2022).

Some studies have revealed the psychological benefits of landscapes that have few plants or minimal liquid water, such as deserts (Yin et al., 2022). Scholarly examination of the shorter-term psychological and physiological responses to these landscapes, and the health outcomes associated with longer-term exposure of living in these settings, may challenge the

consensus that people prefer natural resource-rich environments (i.e., those with abundant plants and/or liquid water). These clues underscore the importance of expanding the definition of nature beyond "greenspace" and "bluespace." These clues also emphasize the need to explore potential mechanisms driving the health benefits associated with exposure to natural landscapes that have been discussed in the nature-health literature less commonly.

The first objective of this narrative review is to develop a framework that categorizes the broad array of natural landscapes that is not based solely on color. The second objective is to review the available literature on the possible health benefits of exposure to natural landscapes that are not dominated by plants or liquid water. The third and final objective is to identify possible mechanisms that might explain how shorter-term and longer-term exposure to these landscapes can promote human health and well-being.

2. Material and methods

Given the novelty of the topic and the anticipated diversity of relevant papers, we employed a narrative approach to identify and summarize the literature. Narrative reviews are qualitative research syntheses that describe the results of other studies without a dominant focus on the statistical significance of the findings (Baumeister and Leary, 1997; Siddaway et al., 2019).

We first identified natural landscapes that were not dominated by plants or liquid water but were discussed as restorative (or therapeutic) landscapes. We studied the keywords in the nature archetypes identified by Scandinavian researchers Ottosson and Grahn (2021) and the nature interactions identified by North American researchers Kahn et al. (2012). Additionally, we referenced the findings of a scoping review on therapeutic landscapes (Taheri et al., 2021) and a book on the health benefits of exposure to eight types of natural landscapes (Loewe, 2022).

Keyword searches were then conducted in three databases: Scopus, Pubmed, and Web of Science. The keywords included "brown space*", "brownspace*", "desert*", "arid", "mountain*", "ridge*", "bedrock", "boulder*", "big rock*", "rock formation*", "rock outcrop*", "gray space*"," grayspace", "grey space*", "greyspace*", "white space*", "whitespace*", "snow-cover*", "artic", "Antarctic", "red space*", and "redspace*".[1] We screened titles and abstracts for empirical, peer-reviewed articles published in English that included some form of exposure, along with psychological responses, physiological responses, or health outcomes (i.e., incidence/prevalence of disease, illness, or mortality). Additional articles were retrieved by screening the authors' personal libraries and using ancestry-search methods (i.e., forward and backward searches) (Nørgaard et al., 2022).

All studies of natural landscapes aside from those dominated by plants or liquid water were considered. Specific components of nature (e.g., animals aromatic essential oils) were excluded since our focus was on entire landscapes that existed in the physical world or were presented in simulations (i.e., pictures, movies, or virtual reality) (Browning et al., 2020). We excluded environments usually unavailable to the public, such as outer space and deep underwater landscapes. All authors discussed the classification and inclusion of potential non-green and non-blue natural landscapes. Disagreements were resolved by consensus.

Since the impacts of exposure could be regulated by the duration of exposure (Shanahan et al., 2016), we followed the approach of previous reviews by collecting information from the included papers about any reported health benefits and presenting mechanisms by shorter-term vs. longer-term exposures. Shorter-term exposure refers to a singular experience that lasted from a few minutes to a few hours or a whole day (Barton and Pretty, 2010), such as laboratory or field experiments (Mason et al., 2022; Roberts et al., 2019). Meanwhile, we refer to longer-term exposures as more than a day of exposure or years of living in a landscape.

[1] In keyword searches, the "*" symbol represents any group of characters following the initial string such as plural, adjective, and verb versions of a noun (i.e., "deserts" and "desertification" would be captured by "desert*"; "snow-covered" would be captured by "snow-cover*").

3. Results and discussion

3.1. Types of natural landscapes and health benefits

We observed that most natural landscapes consist of one to three components: water, plants, and rocks and minerals (Fig. 1). Water covers over 70 % of the earth's surface, and plants occupy over 30 % of the land (Congalton, 2021). Plants are largely limited to regions with favorable climatic conditions, water, or sunlight; otherwise, water, rock or minerals are often dominant. Geologic processes including physical and chemical weathering cause rocks or minerals to appear as bedrock, outcroppings, formations, debris, sand, lava fields, and soil. Water can exist in three states: liquid, solid, and gas. Liquid water only exists in a limited temperature range, such that polar regions and landscapes at higher latitudes during winter can be covered with solid-state water (i.e., ice and snow). In these cases, landscapes are dominated not by a single component but by multiple components (i.e., snow-covered boreal forests). Due to the complexity of these layered landscapes and scarcity of available studies, we focused our review on landscapes dominated by a single component and resultant psychological or physiological responses from exposure.

3.1.1. Landscapes dominated by water in a solid state

Water-dominated landscapes usually refer to freshwater or marine landscapes, such as oceans, lakes, canals, or rivers (White et al., 2010). However, marine, freshwater, and even terrestrial areas can be covered with ice or snow, representing landscapes visually different from those shaped by liquid water (Fig. 2). For example, ice and snow are the main components to which people entering the Arctic or Antarctic are exposed. Likewise, snow and ice may dominate other landscapes in winter, particularly in high altitude or latitude areas (e.g., frozen alpine lakes, snowy mountains, tundra, alpine meadows, and cold deserts) (Fig. 2). These landscapes can be considered something other than "bluespace" given their colorful shades of white and gray. Only a few clues have indicated the health benefits of exposure to these landscapes.

We found little evidence to support the beneficial effects of shorter-term exposure to landscapes dominated by solid water. Still, ice and snow are regarded as a major tourism resource (Wang and Zhou, 2019). The beauty and fascination of frozen landscapes are well documented (Brooke and Williams, 2021; Duffy, 2013; Lengen, 2015), including in polar landscapes (Shah, 2015; Summerson and Lieser, 2018), which may explain why many tourists visit polar spaces for sightseeing (Bauer, 2013). Thus, although not well studied, the aesthetic values of polar spaces may be associated with emotional benefits.

In addition to polar spaces, alpine landscapes in the European Alps, Pyrenees, Himalayans, Andes, and Rocky Mountains are often covered with ice or snow. Such landscapes attract many visitors and have motivated glacier tourism (Wang and Zhou, 2019). Some scholars have suggested that

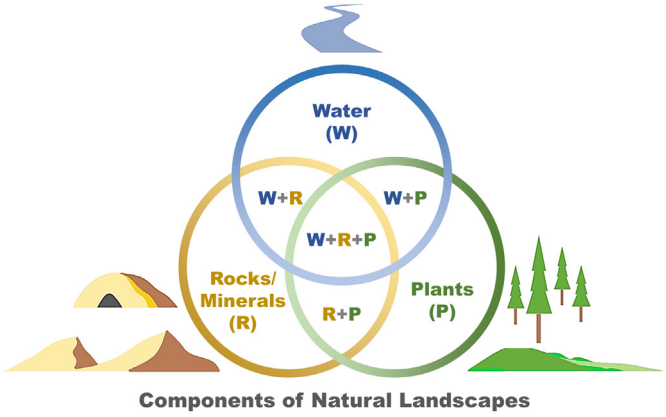

Fig. 1. Most natural landscapes are composed of water in its liquid or solid state, plants, rocks/minerals, or a combination of the three.

Fig. 2. Examples of landscapes dominated by water in a liquid (1–3) or solid-state (3–9).

glacier tourism and outdoor recreation activities in snow-covered environments (e.g., hiking, climbing, mountaineering, and skiing) promote fitness and generate emotional and social benefits (Burtscher et al., 2019; Finkenzeller et al., 2011; Müller et al., 2011). Nevertheless, we found little empirical evidence of other health benefits.

Clues to the health benefits of longer exposures to landscapes dominated by solid water can be obtained from studies of expeditions and deployments. Zimmer et al. (2013) conducted a systematic review of Antarctic psychological research between 2000 and 2010. The review concluded that improved emotion, mood, and a decline in factors contributing to psychological functioning disturbances were possible benefits of Antarctic experiences. Later studies underlined personal growth as a positive outcome resulting from living in polar spaces. For instance, one study concluded that personal strength and other aspects of personal growth were perceived benefits of Antarctic deployment (Blight and Norris, 2018). Studes in the Artic found similar results. Kjærgaard et al. (2017) studied six two-man Danish military teams deployed in the Arctic and found increased personal strength after their time there. Another study compared 384 navy soldiers assigned to Antarctica with 2,396 counterparts assigned elsewhere and found Antarctic soldiers showed relatively stronger health and wellbeing gains over the winter season (Palinkas, 1991). Nevertheless, it should be noted that polar expeditions or deployments are not akin to tourism and have different risk levels. Expedition members or soldiers are selectively recruited and trained and may have higher adaptability to extreme environments (Otani et al., 2004). Possible self-selection bias in these past investigations (Heckman, 1990) might have inflated the observed longer-term benefits of polar experiences.

3.1.2. Landscapes dominated by rocks and minerals

Rock and mineral-dominated landscapes are usually present in areas not covered by plants and water. According to ecosystem classifications (Keith et al., 2020), these landscapes mainly include deserts (terrestrial) and caves (subterranean) (Fig. 3). Deserts can include cold and dry-heat landscapes. Cold deserts are usually present in high altitude or latitude areas that are dominated by ice/snow in the winter and rocks/minerals in the summer. Dry-heat deserts are the one better known by most human populations and present in tropical and temperate areas. Based on our review of the extant literature, only the dry-heat deserts have been studied for their potential health benefits. These rock and mineral-dominated landscapes can include sediment (i.e., soil, sand, and gravel), rock faces (i.e., slabs,

Fig. 3. Examples of landscapes dominated by rocks and/or minerals.

cliffs, and boulders), loose rocks (i.e., talus, scree, and glacial moraine), and unique erosional forms (i.e., towers, domes, spires, blocks, rills, grikes, clints, and hoodoos) (Migoń et al., 2017).

3.1.2.1. Deserts. Deserts may appear to hold little value, given their lack of plants or water and life. However, deserts are prominent types of natural environments on Earth and home to more than 20% of the global human population (Tchakerian and Pease, 2015). Due to global climatic changes and resulting desertification, desert exposure is projected to increase in the coming decades (Huang et al., 2015). Deserts are also valuable tourism resources (Michopoulou et al., 2021).

Some simulation studies have also observed positive outcomes resulting from desert exposure. College students from the Eastern Province of Saudi Arabia exposed to a 1-min coastal desert video (an environment familiar to this population) showed better performance on a subsequent memory task than students showed videos of a temperate forest (a less familiar environment) (Pilotti et al., 2019). Nursing students from El Paso, Texas, U.S., who viewed a 10-min 360-degree video of a desert in virtual reality (VR) showed similar levels of stress recovery to those students who viewed a 360-degree video of a public park with trees and grass (Yin et al., 2022). U.S. adults have also reported that exposure to a desert image is less depleting and stressful than exposure to a built-up urban center (Shalev, 2016). In a desert-based walking program in Israel, themes of physical and mental well-being (i.e., relaxation, peacefulness) were expressed across a diverse range of participants, including those who previously disliked deserts (Teff-Seker and Orenstein, 2019).

We found one experimental study of longer-term exposure to deserts. Participants' brain activity during a 4-day trip to Utah, U.S. showed reduced posterior alpha power, suggesting their attention was directed by the environment (Hopman et al., 2020). A study in Kenya revealed that living in the desert landscape supported physical and mental well-being by offering freedom of movement and a sense of peace (Dan et al., 2021). Similar findings have been observed along the Israeli-Jordanian border (a desert area), where desert landscapes were described as contributing to stress relief and fueling nature affinity among local residents (Sagie et al., 2013). Spatial epidemiology studies have found mixed evidence for the health benefits of living in desert areas. For instance, in a study of students' homes in El Paso, Texas, U.S., associations of residential non-built up impervious areas (i.e., bedrock and sand) with incidence of depression and diabetes were mixed (Nazif-Munoz et al., 2020; Olvera-Alvarez et al., 2021).

Some medical therapies have originated in desert landscapes. Uyghur sand therapy is a traditional Chinese medicine technique created by the Uygur ethnic group that uses sand heated by the sun to cure chronic osteoarthritis (Wang et al., 2018). Such therapy usually requires repeated treatments, so it can be considered a longer-term exposure. One study observed that participants reported healing benefits resulting from the haptic sensations (tactile and kinesthetic) of burning, heat, and swelling while touching hot sand (Wang et al., 2018). Another study by Niyazi (2002) documented 13,115 cases of sand-based therapy in deserts in Xinjiang, China. Findings suggested that sand-based therapy may help with arthritis, rheumatoid arthritis, hyperosteogeny, sciatica, and lumbar disc protrusion. Efficacy for treating these symptoms related to these conditions was reported to be as high as 90% (Niyazi, 2002). Controlled animal trials have further revealed that Uyghur sand therapy might alleviate cartilage inflammation and enhance bone strength (Hu et al., 2015; Kahal et al., 2009), although the quality of evidence from human trials is limited.

3.1.2.2. Caves. Caves are subterranean rock/mineral-dominated landscapes that lack plants due to insufficient sunlight. We found no evidence to suggest benefits of shorter-term exposure to these landscapes. However, like deserts, caves have some aesthetic qualities that might be beneficial. For example, caves with such features as stalagmites and stalactites attract more than 70 million visitors every year globally (Chiarini et al., 2022). Given their widespread allure and appeal, caves may promote some positive emotional responses.

Cave climates also may bring a series of respiratory health benefits due to their unique air qualities. Such potential benefits have fueled multiple interventions, which have been called “speleotherapy” and “halotherapy”. Speleotherapy involves breathing the air in the unique climates of caves to treat respiratory conditions (Freidl et al., 2020) while halotherapy involves breathing air with micronized dry salt in an enclosed space that mimics salt caves (Rashleigh et al., 2014). Since such therapies have been developed for curing chronic respiratory issues and usually require repeated and extended exposures, they can be considered longer-term exposures (Beamon et al., 2001). Numerous studies have underlined the potential of such therapies in treating allergic rhinitis, asthma, and chronic obstructive pulmonary disease (Beamon et al., 2001; Eslaminejad et al., 2017; Freidl et al., 2020). Also, owing to the cave climates, mitigation of skin allergies is believed to be another benefit (Lăzărescu et al., 2014).

Other evidence suggests that longer-term exposure to caves may benefit mental and physical health. A 19-day intervention revealed that speleotherapy might be conducive to reducing anxiety and increasing walking ability (Kendrová et al., 2016). Another 12-week study reported that speleotherapy helped athletes enhance their athletic performance, such as increasing boxers' punch speed, jump, reaction, VO_2max (how efficiently someone uses oxygen during exercise), and balance (Söyler et al., 2021). Salt therapy, an extension of speleotherapy in caves dominated by salt crystals, has been claimed to provide relaxation, a calm mind and emotions, and feelings of revitalization and refreshment (Shah, 2019).

3.2. Mechanisms driving health benefits

The normative perspective within evolutionary psychology suggests people tend to prefer landscapes that are abundant in elements humans have utilized for survival, such as water for drinking and plants for food/shelter. The existence of health benefits provided by natural landscapes that are not rich in life-supporting resources may therefore seem counterintuitive. Nevertheless, multiple theories used to explain the health benefit of nature may extend to natural landscapes not dominated by plants or liquid-state water, while other theories and pathways may be more unique to the natural landscapes discussed in this review. According to a widely referenced theoretical framework developed by Markevych et al. (2017), three dimensions link nature exposure to human health: reducing harm, restoring capacity (i.e., restorative effects), and building capacity (i.e., instorative effects). Harm reduction refers to the functions of some natural landscapes (e.g., tree-rich areas) in mitigating noise, heat, air pollution, and other stressors (Wolf et al., 2020). Restoring capacity (or restorative effects) refers to recovery from negative states, impacts, or deficient conditions, such as attentional fatigue or stress. Building capacity (or instorative effects) refers to natural landscapes' ability to promote health through behavior and psychological states absent of a deficient condition. Examples of natural landscapes' building capacities include promoting social cohesion and physical activity (Kondo et al., 2018; Korpela and Ratcliffe, 2021).

Although the three-domain framework was developed for plant-rich landscapes (“greenspaces”), some parts (restoring and building capacities) can be adapted to describe the potential mechanisms for natural landscapes not dominated by plants or liquid-water. We found no evidence for the “reducing harm” dimension within the landscapes we studied but retained this dimension in our framework to recognize it may emerge in future research. To highlight the potential risks posed by these landscapes, we followed Marselle et al. (2021) and added risks (i.e., dangers) and deficiencies (i.e., situations where or populations for whom health benefits are not observed) to illustrate possible adverse effects of exposure (Fig. 4).

3.2.1. Restoring capacities

Attentional resources can be rapidly consumed in city living, and urban residents usually face attentional depletion (Sullivan and Li, 2021; White and Shah, 2019). Natural landscapes have been shown to help recover such resources. Attention restoration theory (ART) is a widely used theory for explaining the psychological benefits of shorter-term exposures to natural landscapes. ART describes how certain landscape characteristics can improve

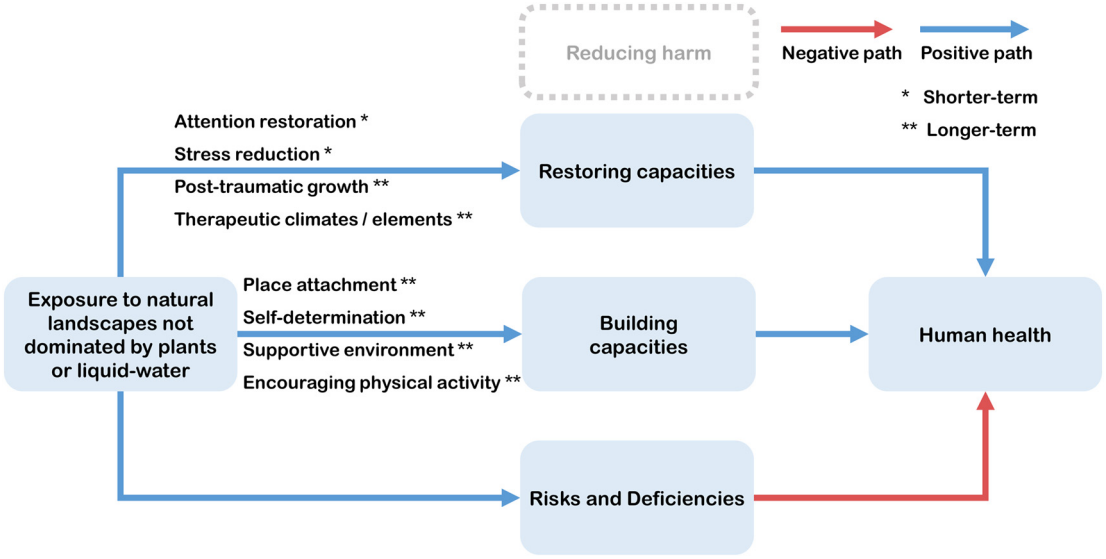

Fig. 4. Hypothesized pathways linking exposure to natural landscapes, including those not dominated by plants ("greenspace") or liquid-water ("bluespace"), with human health. Notes: shorter-term vs. longer-term exposure detonated by * and ** respectively. Reducing harm is a common pathway in other nature-health research (Markevych et al., 2017) and was retained to recognize that this pathway may emerge in future research on natural landscapes not dominated by plants/liquid-water, despite little evidence for its role to-date.

cognitive functioning through capturing people's attention involuntarily (Kaplan, 1995). The four characteristics that facilitate attention recovery include being away (providing an escape from habitual activities), soft fascination (aspects of the environment that capture attention in a gentle and effortless manner), extent (richness and coherence of an environment to form the feeling of a complete and different world), and compatibility (the environment fits one's purposes) (Kaplan, 1995). ART does not assume restoration can be only facilitated by environments dominated by plants and liquid water, as these characteristics can exist in a wide range of environments. Polar and/or alpine landscapes, deserts, and caves may not be as fascinating as other natural landscapes due to the lack of desirable natural elements and a smaller number of colors and low-level features, although notable exceptions exist. Still, these landscapes can offer visitors with scenery that is different from their daily lives and more unique than plant or liquid-water-dominated landscapes, thus creating strong senses of being away from everyday routines and worries (Pilotti et al., 2019). Several studies have also underlined the beauty and physical appeal of some deserts (Gutberlet, 2019) and polar spaces (Cajiao et al., 2022; Powell et al., 2012; Summerson and Lieser, 2018). Aesthetics is also a key element of cave tourism (Kim et al., 2008). All of these landscapes may contain beautiful objects with low levels of movement, thereby attracting visitors' undirected or involuntary attention and in turn producing restorative directed or voluntary attention benefits.

Environmental stressors (e.g., crowding, noise, and air pollution) also dominate urban areas that house the majority of the world's population (Browning et al., 2022; Cohen et al., 2013). Stress reduction theory (SRT) describes how non-threatening natural environments in which humans evolved may activate the parasympathetic nervous system in ways that reduce stress and autonomic arousal (Ulrich, 1983; Ulrich et al., 1991). More specifically, SRT posits that human beings have rapid, biologically prepared emotional responses to natural environments. Such biologically prepared responses can facilitate subsequent approach-avoidance behaviors (e.g., escape, stay in, and explore) and the induction or reduction of stress. Because a stress state is energy consuming, if a threat situation is resolved and the person enters a non-threatening natural environment, the adaptive response is to reduce stress levels quickly to restore energy and explore the resources in the landscape. Since plant and water-rich environments are not the only landscapes where humans evolved or still live (Hägerhäll et al., 2018; Zhang et al., 2021). Deserts, caves, and solid water landscapes without the presence of immediate threats (e.g., poisonous insects, snakes, and precipices) may also provide adaptive responses that would also be energy saving for subsequent exploration. Therefore, urban residents may experience mental health benefits when they are exposed to deserts, caves, and solid water landscapes.

Post-traumatic growth theory, which relates to recovery from a deficient state, may help explain the benefits of longer-term exposure to solid-water-dominated landscapes, caves, and deserts. This theory suggests that people who endure psychological struggles following adversity may see positive growth afterward. We placed this theory in the restoration dimension as it requires pre-induced psycho-physiological declines to generate compensation or "super-compensation" (recovering to higher levels than baseline). Landscapes without drinkable water and plants are generally harsh for animals, including humans. Unlike visitors who briefly visit these landscapes for recreation, residents/travelers who take longer stays may experience multiple environmental stressors. For instance, snow and ice may make outdoor physical activities very physically and mentally challenging (Chapman et al., 2019; Larsson and Chapman, 2020). Dust may also cause respiratory distress in deserts (Goudie, 2014). Such stressors threaten visitors even if modern technologies (i.e., protective clothing, climate-controlled shelter, and regular provision of food and water) have partially addressed resource constraints. But these stressors also present unique opportunities for personal growth. Successfully overcoming the challenges of over-wintering have been reported as a reason for the mental improvement during long-term stays in the Antarctic (Jenkins and Palmer, 2003). Overcoming stressors also appears to be a common reason for the observed positive effects on health and wellbeing among polar expedition members (Palinkas and Suedfeld, 2008; Zimmer et al., 2013). Blight and Norris (2018) have already explained some of the positive consequences of polar space exposure with this theory. Although we found no scholars reporting post-traumatic growth in deserts, we posit that similar effects may exist since these landscapes are similar in their intensity of stressors and demands.

In addition to psychological aspects, some medical treatments for chronic respiratory and allergy symptoms are also based on landscapes' physical features. Specifically, caves generate unique health promoting mechanisms due to their micro-climates. These climates may help to regulate the immune system and hormone secretion (Bilha and Simionca, 2013; Nagy et al., 2009). According to Freidl et al. (2020), the climates in caves include five therapeutic features. The first is the high relative humidity (Lunghi et al., 2017), which can benefit the respiratory system. The second

is cave aerosols, which may contain some health-promoting ions (e.g., Ca2+) that can treat infected areas in asthmatic lungs (Alföldy et al., 2002). The third is the absence of air pollutants resulting from caves' unique structure (Kertész et al., 2002). The fourth is radiation and ionization. Certain radon levels (a radioactive noble gas of natural origin commonly present in caves) may help treat pain symptoms caused by chronic degenerative diseases (Maier et al., 2021). The last is the lack of ozone due to no sunlight (Korzhe, 2017).

In Uyghur sand therapy, desert sands can deliver heat to the human body effectively and safely under proper procedures (Lina et al., 2005). Such haptic sensations and corresponding physiological responses can increase blood flow in major arteries and decrease platelet deposition (Han et al., 2019). Some practitioners have also surmised that the elements in desert sands, such as silicon dioxide and magnetic particles, are physiotherapeutic materials of Chinese medicine that positively affect physiological responses and promote physical health (Niyazi, 2002).

3.2.2. Building capacities

Supportive environment theory (SET) may help explain how novel natural landscapes can build health capacity among individuals exposed to them. Supportive environments refer to landscapes that are easy to understand and manage. SET suggests that people need such environments to maintain physical and mental health (Grahn and Stigsdotter, 2010). Although SET has been employed to explain the benefits of plant-dominated landscapes, it may also relate to the psychological benefits of deserts. One's perception of landscapes is not only bonded by genes but also fostered over the life course. For tourists who are unfamiliar with deserts, they may be places where feelings of excitement mask feelings of relaxation, thereby activating the innate responses of the sympathetic nervous system (Terzano and Gross, 2020). In contrast, the millions of people around the world who grew up in deserts may find these ecosystems commonplace and familiar. Thus, a desert could be a supportive environment for local residents. Nazif-Munoz et al. (2020) and Yin et al. (2022) argued that desert residents may be accustomed to the rocky natural elements and tend to feel safe within them. Indeed, many people have written passionately about the unique benefits afforded by prolonged exposure to nature in desert landscapes (i.e., Abbey, 1968).

It is unclear if SET applies to solid-water-dominated landscapes. One study revealed that some people who are accustomed to polar conditions might feel snow and ice are manageable parts of everyday life (Finlay, 2018). Such evidence comes from a study in Minnesota, U.S., which has only intermittent snow and ice, so it offers only indirect evidence to support the relevancy of SET.

Caves are special because there are very few cave residents in the world. China has villages that were settled in natural caves for long periods of history. It is reported that some people still living in these caves today are unwilling to move out because they are familiar with that environment (Zhou, 2019). We speculate that caves can also be supportive environments for these residents.

Relatedly, place attachment may explain some benefits acquired from familiar natural landscapes. Place attachment is composed of multiple dimensions, including person (personal meanings of place), process (affective, cognitive, and behavioral psychological components of attachment), and place (i.e., physical elements of a setting; Scannell and Gifford, 2010). Place attachment can occur in landscapes of varying significance, such as landscapes bonded with personal experiences, particularly in childhood (Riley, 1992). Attachment to place can also help to build resilience and transformative capacity within these systems (Larson et al., 2018; Masterson et al., 2017). In “greenspace” research, place attachment has been described as a functional attachment associated with various recreational activities in a place, which partially explains why people prefer greenery in their neighborhood (Zhang et al., 2015). For local residents, landscapes with abundant solid-state water or rocks and minerals may also provide places for recreational activities to happen. These landscapes usually lack noise and other disturbances due to limited traffic or human activities. Youth in particular may have positive experiences that foster attachment to such places (Scannell et al., 2016). Place attachment has been empirically linked to health and wellbeing (Molcar, 2006; Rollero and De Piccoli, 2010), which can translate to stronger health outcomes as a result of prolonged exposure to landscapes that are emotionally meaningful to people.

Yang et al. (2022) proposed that self-determination theory (SDT) may explain the enhanced psychological well-being of nature exposure - a relationship that may translate to the diversity of landscapes discussed here. Basic psychological needs theory, as a mini-theory of SDT, describes how autonomy (feeling capable of making one's own decisions and actions), competence (feeling capable of accomplishing one's desired outcomes), and relatedness (feeling connected to and accepted by others) are basic needs for achieving wellbeing and optimal function (Deci and Ryan, 1985; Jacobs and Jacobs, 2000; Ryan and Deci, 2017). SDT may relate to nature exposure in three ways. First, natural environments pose fewer social demands (e.g., everyday routines and social judgment) and thus satisfy individuals' need for autonomy by offering more freedom to engage in self-directed activities. Relatedly, natural environments may offer a sense of control, and therefore competence, particularly in the landscapes discussed here through challenging recreational activities (e.g., rock climbing, cave exploration, and snow sports) that may help individuals demonstrate mastery and gain control over their lives (Crockett et al., 2020). Lastly, nature may be considered a special type of social entity. Enhancing connections between humans and nature may thereby satisfy the human need for relatedness (Cheng and Monroe, 2012; Kellert and Wilson, 1993). SDT has only been tested in a single experiment with a shorter-term exposure to nature. However, Yang et al. (2022) underlined its benefits may extend to populations preferring a variety of types of natural landscapes due to cultural differences. Correspondingly, the benefits related to SDT may be particularly relevant to populations most accustomed to landscapes not dominated by plants or liquid-water because of their longer-term exposures to these landscapes.

Some longer-term health benefits may also relate to landscapes' physical features, especially if these features encourage physical activity. Similar to many landscapes dominated by plants or liquid-water, landscapes rich with rocks or ice may offer places for physical activity and sports. Solid-water-dominated landscapes may be necessary for activities like skating and skiing. These landscapes may motivate nature-based outdoor exercise among some newcomers and locals, particularly during milder weather (Wagner et al., 2019). In addition to cardiovascular benefits related to exercise, snow sports may be conducive to positive emotional arousal, social bonding, and feelings of accomplishment, particularly in the presence of others (Mirehie and Gibson, 2020). Desert landscapes are usually smooth and open, which may also provide some novel physical activity opportunities. Residents in Kenya reported that the desert topography allowed freedom of movement and enhanced physical wellbeing (Dan et al., 2021). Such topographic elements are foundations of desert sports that benefit both locals and tourists (Abyar et al., 2014; Hashemi et al., 2020; Yan, 2014).

3.2.3. Risks and deficiencies

Despite the many possible health benefits, natural landscapes not dominated by plants and/or solid-water also many deficiencies and potential risks, like in all natural landscapes (Marselle et al., 2021). Some scholars refer to these negative aspects as ecosystem disservices (Oosterbroek et al., 2016). Snow and ice may limit mobility, evoke senses of boredom, fear, and isolation, and cause concerns related to safety and vulnerability (Finlay, 2018). Snow and ice might also aggregate depression and seasonal affective disorder and even increase suicide risk (Leppämäki et al., 2002; Rind, 1996). People engaging in ice and snow-covered alpine-based outdoor recreation are also prone to falling injuries (Selig et al., 2012), frostbite (Ströhle et al., 2018a), mountain sickness (Imray et al., 2010), and lightning strikes (Ströhle et al., 2018b). Activity in deserts can place people at risk of dehydration, hyponatremia (electrolyte imbalance due to excessive water drinking), heat stroke, and even hypothermia (Elbaz et al., 2008; Krake et al., 2003; Shopes, 1997). Desert dust may carry bacteria (Ruiz-Gil et al., 2020) and retreating lake beds may expose heavy metal

depositions that threaten health (Han et al., 2004; Riches, 2019). In caves, excessive levels of radon may increase cancer risk (Maier et al., 2021). Many caves are inhabited by bats, and bats can be hosts for many viruses, which increases the risk of infections (Lottenberg et al., 1979; Willoughby et al., 2017). Such occurrences underline the necessity of risk management in these landscapes when considering nature-based health interventions.

Counterevidence to the potential health benefits of nature exposure in environments that are not dominated by plants or liquid-water also exists. For example, a study of Texas, U.S. college students reported that images of deserts were less restorative than images of other terrestrial biomes, including tundra and different types of forests (Han, 2007). Another study found U.S. adults reported decreased confidence in their ability to change negative habits and increased feelings of depletion and stress when shown a desert image compared to an image dominated by liquid water (Shalev, 2016). Such contradictory evidence may be related to humans' inherent familiarity with resource-rich landscapes and the need to test responses among residents more accustomed to landscapes outside the conventional spectrum, such as deserts.

Several health-promoting factors present in landscapes with abundant plants or liquid water may not extend to other types of natural landscapes. Biological factors such as environmental microorganisms and negative oxygen ions, as well as beneficial volatile biogenic compounds (VOCs) generated by plants (Roviello and Roviello, 2021; Stanhope et al., 2020), may be nearly absent in polar regions, caves, and deserts. Climate regulation, aerosols, and negative ions generated by water movement and water-related organisms can also be absent in landscapes without liquid water (White et al., 2020).

Therefore, more clarity is needed with regard to potential health-promoting factors, risks, and deficiencies in landscapes not dominated by plants and/or solid-water. Such knowledge would allow for risk-benefit calculations when developing nature-based therapies and specific health promotion interventions.

3.3. Limitations and future research directions

Due to the types of included studies, we chose to use a narrative review instead of a systematic review to offer insights into this topic. Narrative reviews are suitable for describing the current state of a focal area and surveying newer study areas not yet addressed (Ferrari, 2015). Narrative reviews also have some inherent limitations, such as selection and interpretation bias (Animasahun and Chapman, 2017). Even though we tried to use a systematic search method and complementary methods to identify studies, our search strategy may not have been comprehensive. Our selection of keywords from existing research on the broad array of natural and possibly therapeutic landscapes may have missed terms used to describe these landscapes by some cultures (Loewe, 2022; Kahn et al., 2012; Ottosson and Grahn, 2021; Taheri et al., 2021). Furthermore, we could not assess the overall direction, strength, or robustness of the potential health effects resulting from exposure due to the diversity in research designs, exposure assessments, analytical methods, data types, and health outcomes presented in the identified literature. Instead, we could only offer circumstantial evidence and tentative conclusions that warrant additional, rigorous investigation (Pae, 2015).

The available evidence for the health benefits of exposure to natural landscapes not dominated by plants/liquid-water is largely drawn from observational research prone to residual confounding and self-selection bias. Similar challenges are present in research on health benefits linked to other types of natural landscapes. Further examinations should use more rigorous sampling techniques and study designs, such as following cohorts over time and conducting randomized clinical trials (Frumkin et al., 2017). Still, given the expense and challenges of these approaches, we recognize value in additional observational research given how few studies exist for each exposure-outcome pairing.

Consistent operationalizations of nature exposure are needed to better compare findings across studies. We identified one attempt at quantifying natural rock/mineral cover (Nazif-Munoz et al., 2020; Olvera-Alvarez et al., 2021) and no attempts at quantifying snow or ice cover despite measures being available in remotely sensed datasets similar to what is used to quantify plant cover (Gao et al., 2010). We also identified no attempts at quantifying exposure to rocks/minerals or ice/snow cover using street view imagery. These measures would allow complementary or even improved exposure estimates given their ability to measure what can be seen at eye-level (Kang et al., 2020).

Future work is also needed to validate and expand the mechanisms linking exposure to health outcomes. The mechanisms we presented are largely adapted from studies and theories focused on plant-rich landscapes (Markevych et al., 2017; Marselle et al., 2021). Some of the arguments in favor of these mechanisms are also based on indirect evidence. Given how understudied this body of research is relative to other environmental exposures (e.g., air pollution and water quality), we anticipate undiscovered or under-discussed mechanisms to emerge. For example, while we did not identify evidence for these natural landscapes reducing harmful exposures, future research could investigate this possibility. The mechanisms we presented are also likely to be refined as the quantity and quality of this body of literature grows.

Nature and health scholars should embrace the complexity of natural landscapes, which often leads to co-occurring exposures to multiple components of nature for humans in these settings (i.e., plants, water, and rocks/minerals). Few attempts have been made to measure vegetative and rock/mineral cover simultaneously (Nazif-Munoz et al., 2020; Olvera-Alvarez et al., 2021). We are unaware of attempts to incorporate these components at the same time as water (in its solid or liquid state) in a way that would present exposure to all three components concurrently. Such efforts would fill several gaps and answer key questions related to the health benefits of nature exposure. For example, how much do the health benefits of different types of nature exposure overlap vs. diverge? Do natural landscapes with different components provide a multiplier effect whereby the total is greater than the sum of the individual parts? Does the dosage required to achieve health benefits vary as people are exposed to more diverse natural elements?

The changing of the seasons are likely to modify what components of natural landscapes are present at different times of year and across the lifecourse. For example, a high-alpine mountain landscape in a temperate climate is dominated by rocks – and perhaps even plants – in the summer and by snow and ice during in much of the winter, spring, and fall. Diurnal fluctuations in light levels across various landscapes (e.g., light pollution at night) might also influence health outcomes (Davies and Smyth, 2018). Apart from appearance changes, the health benefits these landscapes afford may change. Although we did not find any studies on the seasonality of our reviewed landscapes, "greenspace" studies may offer some indications. For example, the attractiveness of plant-dominated landscapes can vary with season (Morckel, 2015; Xu et al., 2022). Trees and other forms of vegetation may show heat buffering effects that vary by climate and season (Chun and Guldmann, 2018). By contrast, some rock/mineral-dominated landscapes may be perceived as less attractive or accommodating and increase heat stroke risks due to extreme temperatures in summer months (Varghese et al., 2005). These seasonal variations may be of importance for shorter-term exposures, because visitors may be less aware of the risks compared to residents when they are entering new landscapes (Skinner et al., 2001). Ultimately, seasonal variations could make some of the landscapes we reviewed less beneficial or even harmful (e.g., deserts during daylight hours in summer months). We recommend accounting for seasonal and climatic factors in future studies exploring benefits associated with nature. Ongoing climate change effects should be considered carefully as they may dramatically modify some of the landscapes considered, such as landscapes dominated by solid water and deserts. Time-varying exposure data rather than cross-sectional data should also be used to account for the full range of experiences with natural settings and minimize exposure misclassification.

Finally, the utility of these landscapes for nature-based therapies and specific health promotion interventions warrants critical examination.

Speleotherapy and Uyghur sand therapy are examples of existing interventions with insufficient data regarding their recommended dosage, efficacy, and risk management. In contrast, therapies like forest-bathing or horticultural therapy are more mature and have many empirical research studies (Rosa et al., 2021) and practitioner-oriented articles and books written on their safe administration (Li, 2019; Miyazaki, 2021; Schuh and Immich, 2022). Ultimately, the landscapes we discussed may pose greater risks and challenges than other natural landscapes. Risk-benefit calculations must be made before pursuing therapies in these landscapes at-scale and with the general population (i.e., people less familiar with these landscapes). The extent to which the possible health benefits of exposure outweigh the risks is perhaps the crux of future studies focused on these landscapes. We hope our contributions inspire research on the wide-ranging diversity of natural landscapes that exist, and how nature-based interventions can maximize the health benefits of these landscapes.

4. Conclusions

Our narrative review introduced the potential benefits of certain natural landscapes that are rarely studied in the rapidly growing literature on the health benefits of nature exposure. We presented a new and more comprehensive classification for types of health-promoting natural landscapes that moves beyond color-coding (i.e., "greenspace" and "bluespace"). This classifications focuses instead on natural components, including plants, water, and rocks/minerals. We also reviewed the extant literature on landscapes dominated by solid-state water (e.g., polar spaces) and rocks or minerals (e.g., deserts and caves) to reveal associations of shorter- and longer-term exposure with health impacts. Despite the risks associated with visiting or living in these landscapes, we observed the potential for beneficial psychological and physiological responses as well as physical and mental health benefits, including resources for medical treatment. We posited that restorative and instorative pathways explained the health promotion capacities of these landscapes on the basis of previous frameworks from "greenspace" research (Markevych et al., 2017; Marselle et al., 2021). Further research, including hypothesis-driven longitudinal studies, is needed to strengthen the literature focused on these landscapes, document exposure-outcome pairs, and validate mechanisms linking these landscapes with human health.

CRediT authorship contribution statement

Hansen Li: Conceptualization, Methodology, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Matthew H.E.M. Browning:** Conceptualization, Methodology, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration. **Alessandro Rigolon:** Conceptualization, Methodology, Data curation, Writing – review & editing, Visualization. **Lincoln R. Larson:** Conceptualization, Methodology, Data curation, Writing – review & editing, Visualization. **Derrick Taff:** Conceptualization, Data curation, Writing – review & editing, Visualization. **S.M. Labib:** Conceptualization, Data curation, Writing – review & editing, Visualization. **Jacob Benfield:** Conceptualization, Writing – review & editing. **Shuai Yuan:** Conceptualization, Writing – review & editing, Visualization. **Olivia McAnirlin:** Conceptualization, Writing – review & editing. **Nazanin Hatami:** Conceptualization, Writing – review & editing. **Peter H. Kahn:** Conceptualization, Writing – review & editing, Visualization.

Data availability

No data was used for the research described in the article.

Declaration of competing interest

We declare that we have no conflicts of interest.

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