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Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

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Review

Nature's contributions in coping with a pandemic in the 21st century: A narrative review of evidence during COVID-19

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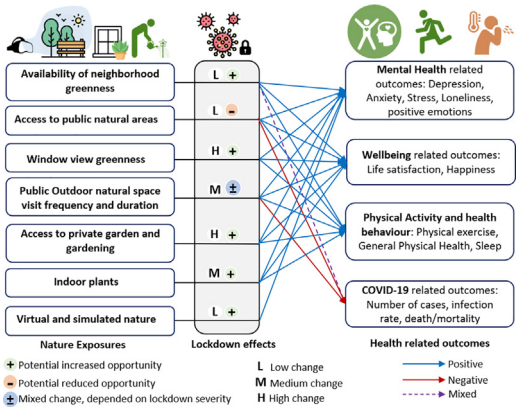
HIGHLIGHTS

- Reviewed studies investigated role of nature exposure on public health during COVID-19.
- During COVID-19, multiple types of nature experienced, nature exposures have generally increased.
- Consistent positive associations between nature exposure and improved mental health observed.
- Nature exposures had mixed associations with physical health conditions.
- Nature-based interventions, design, governance should be promoted to increase nature exposure.

GRAPHICAL ABSTRACT



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ABSTRACT

While COVID-19 lockdowns have slowed coronavirus transmission, such structural measures also have unintended consequences on mental and physical health. Growing evidence shows that exposure to the natural environment (e.g., blue-green spaces) can improve human health and wellbeing. In this narrative review, we synthesized the evidence about nature's contributions to health and wellbeing during the first two years of the COVID-19 pandemic. We found that during the pandemic, people experienced multiple types of nature, including both outdoors and indoors. Frequency of visits to outdoor natural areas (i.e., public parks) depended on lockdown severity and socio-cultural contexts. Other forms of nature exposure, such as spending time in private gardens and viewing outdoor greenery from windows, may have increased. The majority of the evidence suggests nature exposure during COVID-19 pandemic was associated with less depression, anxiety, stress, and more happiness and life satisfaction. Additionally, nature exposure was correlated with less physical inactivity and fewer sleep disturbances. Evidence was mixed regarding associations between nature exposure and COVID-related health outcomes, while nature visits might be associated with greater rates of COVID-19 transmission and mortality when proper social distancing measures were not maintained. Findings on whether nature exposure during lockdowns helped ameliorate health inequities by impacting the health of lower-socioeconomic populations more than their higher-socioeconomic counterparts for example were mixed. Based on these findings, we argue that nature exposure may have buffered the negative mental and behavioral impacts of lockdowns during the COVID-19 pandemic. Recovery and resilience during the current crises and future public health crises might be improved with nature-based infrastructure, interventions, designs, and governance.

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Contents

1. Introduction

On 11 March 2020, the World Health Organization declared the coronavirus outbreak a pandemic, and in February 2022, we entered the 24th month of this global public health crisis. The Severe Acute Respiratory Syndrome Coronavirus (SARS-CoV-2), or COVID-19, has caused loss of life at an unprecedented scale (Dong et al., 2020; Roser et al., 2020). As of January 2022, the COVID-19 pandemic continues in many countries due to the highly contagious variants Delta and Omicron (Lopez Bernal et al., 2021; Wang and Han, 2022). To contain the spread of the infection and minimize strain on health services, governments have imposed restrictions such as lockdowns or other social and physical distancing measures (Atalan, 2020; Meyer et al., 2020). Several studies have documented that such lockdown measures may have reduced the spread of the infection, thus saving millions of lives (Brauner et al., 2021; Flaxman et al., 2020).

Such non-pharmaceutical approaches to combat COVID-19 as lockdowns, self-isolation, and quarantine (hereafter referred generally as lockdown) had positive impacts on death tolls and health service capacities (Pouso et al., 2021; Robinson et al., 2021). Nonetheless, these measures had unintended negative consequences on other health outcomes (Brooks et al., 2020; D'Alessandro et al., 2020; Lippi et al., 2020; Pfefferbaum and North, 2020). Notably, lockdowns may have contributed to the worsening of non-communicable diseases (e.g., cardiovascular disease, diabetes), increasing mental health disorders associated with depression, anxiety, and stress, and diminishing psychological well-being (Lades et al., 2020; Ledford et al., 2021; Mattioli et al., 2020; Pal and Bhadada, 2020). There are numerous reasons for the negative impact of lockdowns on physical and mental health. Key reasons include but are not limited to increased sedentary lifestyle, physical inactivity, infection fears, financial loss, inadequate information, feeling of loneliness and boredom (Brooks et al., 2020; Ledford et al., 2021; Peçanha et al., 2020). In contrast, nature exposure, including contact with blue and green spaces, indoor plants, gardening, have the potential to mitigate against or buffer the negative health consequences with the potential for little/no negative impacts (Mayen Huerta and Cafagna, 2021; Pouso et al., 2021; Ribeiro et al., 2021; Vimal, 2022; Yang et al., 2021).

Numerous reviews have documented the evidence of the potential influence of exposure to the natural environment on human health and wellbeing (Bratman et al., 2019; Frumkin et al., 2017; James et al., 2015; Labib et al., 2020; Rojas-Rueda et al., 2019; Twohig-Bennett and Jones, 2018; White et al., 2020) along multiple mechanistic pathways (Hartig, 2021; Hartig et al., 2014; Markevych et al., 2017; Marselle et al., 2021; Nieuwenhuijsen et al., 2017). In general, these studies reported that nature exposure has positive health effects by mitigating health stressors (e.g., heat reduction), increasing restoration such as stress recovery, and building capacity by encouraging physical activities (Bosch and Sang, 2017; James et al., 2015; Kondo et al., 2018; Markevych et al., 2017). Several studies have also noted that numerous elements of natural environments such as colors (e.g., seasonal variations), patterns (e.g., texture of leaves), scales (e.g., multiple sizes of natural space and elements therein), actual/perceived proximity, and sensory inputs (e.g., visual, auditory, olfactory) have multidimensional benefits on physical and mental health, spirituality, and psychological wellbeing (Benfield et al., 2014; Kaplan and Kaplan, 1989; Kaplan, 1995; Russell et al., 2013).

Several studies have also reported some negative health effects of nature contact, notably through increased exposure to allergens, infectious diseases, and harmful microbiota (Aerts et al., 2018; Marselle et al., 2021). Additionally, studies have noted the potential for adverse effects of nature contact resulting from negative experiences and cultural narratives that evoke painful memories related to segregation and lack of environmental participation. These negative effects are particularly dominant among certain historically disadvantaged groups, such as Black people in the U.S. (Finney, 2014; Heynen et al., 2006). Evidence of the effects (both positive and negative) of nature exposure on human health are primarily documented on pre-COVID studies between 2000 and 2020. These studies mostly indicated strong evidence for overall positive effects of nature exposure on human health and wellbeing (Bosch and Sang, 2017; Bratman et al., 2019; Jimenez et al., 2021; Twohig-Bennett and Jones, 2018). Considering the previous evidence of nature-human health relations, many studies have investigated the impact of nature contact on mental and physical health during and after the COVID-19 within the ongoing period of the pandemic.

Prior to and during the COVID-19 pandemic, certain populations have been more susceptible to mental and physical health problems than others. In particular, racial/ethnic minority people and lower-socioeconomic (SES) groups around the world are more susceptible to all-cause mortality as well as many diseases and illnesses including cardiovascular disease, diabetes,

respiratory diseases, obesity, general physical health, birth outcomes, cancer, and suicide ideation (Braveman et al., 2010; Solé-Auró and Crimmins, 2008; Weinstein et al., 2017). Disadvantaged groups also show higher rates of COVID-19 incidence, mortality, and lingering symptoms in addition to psychological impacts from the COVID-19 pandemic than other groups (Browning et al., 2021; Spotswood et al., 2021; Wenham et al., 2020). These disparities have been explained by disadvantaged populations' worse educational opportunities, lower health care access, and more harmful environmental exposures compared to privileged groups (Weinstein et al., 2017; Woolf and Braveman, 2011). Some health outcomes are also more prevalent or severe among men or women, demonstrating that gender-related health inequities also exist and stem from social, biological, and economic determinants (Vlassoff, 2007). For instance, a longitudinal study indicated that the consequences of the COVID-19 pandemic on mental health have had substantial gender differences (Vloo et al., 2021). During lockdown, women experienced more depression, while men experienced more anxiety (Vloo et al., 2021).

Nature exposure has been identified as a possible environmental factor that could reduce health disparities (Rigolon et al., 2021). In particular, nature exposure might help improve health outcomes for socioeconomic and racially/ethnically vulnerable populations more than for other populations because the former might have more to gain than other groups (i.e., more chronic conditions and diseases to address), are less mobile due to lower vehicle ownership and spend more time in their residential neighborhoods, and have less access to other recreational or exercise opportunities (Braveman et al., 2010; Markevych et al., 2017; Marmot et al., 2008; Robinson et al., 2018). Differences in nature-health associations by gender/sex might result from gender norms, child-rearing responsibilities, and biologic susceptibilities to environmental toxins (Bolte et al., 2019). A recent systematic review by Sillman et al. (2022) noted that nature exposure tends to have stronger associations with physical health outcomes for women than for men. Such effects are more evident in terms of green land cover (i.e., generalized measures of greenness like normalized difference vegetation index [NDVI]) than for public green space (i.e., public parks). Additionally, the authors noted the protective effect of greenspace exposure was stronger for women than men in European and North American countries. The authors suggested that greenspace could help reduce some gender-based health disparities (Sillman et al., 2022).

Among the nature exposure and health studies published during COVID-19 pandemic, the majority indicated positive associations between nature exposure and human health with some variation in effect by the severity of lockdown, types of nature exposure, amount of nature contact, and sociodemographic and racial/ethnic composition. However, some studies also reported mixed or inconsistent findings regarding changes in the amount of nature contact during lockdowns, positive vs. negative impacts on health from nature contact, and disparities in nature contact and related health impacts (Browning et al., 2021; Corley et al., 2021; Larson et al., 2021; Y. Lu et al., 2021a; Pan et al., 2021; Spano et al., 2021). Considering these variations in evidence among the existing studies, it seems timely and reasonable to review the overall contributions of nature in coping with the pandemic in terms of varying health benefits of nature exposure. To our knowledge, there is no review that has synthesized the evidence of nature's contributions in dealing with the consequences of the COVID-19 pandemic and none that have critically discussed the ways nature-based interventions and design can aid in coping and recovering from current and future pandemics. Considering the mounting number of studies in this timely field of study, we aimed to synthesize the evidence for nature contact during the COVID-19 pandemic and its consequences on human health. Specifically, we investigated the following research questions using a narrative review approach:

1. Which types of nature exposure did people experience during lockdown?
2. How did nature contact change during the lockdown?
3. How was nature exposure associated with mental, physical, and general health during lockdown?
4. How did associations between nature exposure and human health during lockdown vary by age, gender, socioeconomic status, and race/ethnicity?

With the increasing risk of future zoonotic pandemics (Bonilla-Aldana et al., 2020; Quammen, 2012), public health officials, urban planners, and policymakers need to rethink the importance of nature in increasing resilience and adaptive capacity for future emergencies (Mell and Whitten, 2021; Moglia et al., 2021). In the context of the One Health Approach, which recognizes that human health is closely related to animal and environmental health (Bonilla-Aldana et al., 2020; Zinsstag et al., 2011), this review focuses on the environmental and human health aspects of the framework. It summarizes the evidence of the interconnections between human health and the natural environment during the global public health crisis of COVID-19. This review, therefore, concludes with a discussion of how nature exposure might be considered as a coping mechanism against future pandemics and epidemics to promote public health.

2. Methods

We conducted a narrative review synthesizing the evidence from both quantitative and qualitative studies (Ferrari, 2015). We adopted a narrative review approach instead of a systematic review approach because the former allowed us to summarize and link together studies with varying methodological and theoretical conceptualizations (Baumeister and Leary, 1997; Holland et al., 2021). The studies relevant to this review had heterogeneous study designs, and many did not apply established data collection protocols and theoretical conceptualizations.

To identify relevant articles, we conducted keyword searches using Scopus, Web of Science, and PubMed. The keywords were divided into two groups: (1) Nature contact ("greenspace", "greenness", "green space", "outdoor", "greenery", "blue space", "park"), and (2) COVD-19 related ("COVID", "COVID-19", "Coronavirus", "Pandemic"). Details of search strings can be found in the Appendix. These keywords were intended to identify articles that helped us answer our four research questions. We searched and selected peer-reviewed research articles from these keyword searches that were written in the English-language and published between 1st March 2020 and 31st December 2021. We identified additional articles using a snowball search method by screening the references cited in the articles we found from our keyword searches. We did not include pre-prints since these studies were not yet officially accepted by the scientific community through the peer-review process; therefore, we could not confirm their robustness.

During the initial screening of the titles and abstracts, we excluded studies if they: (1) were about unrelated topics (e.g., title or abstract did not match our four research questions); (2) focused on animals and disease ecology, (3) were not original research. During our evaluation of the full texts, we excluded studies if they did not: (1) clearly indicate the nature contact and exposure types such as natural environment visit frequency, green view, or gardening; (2) directly or indirectly measure or observe health outcomes and health behavior; (3) focus on investigating the relationships between nature exposure and health outcomes and behavior during the COVID-19 pandemic. Although we carefully extracted articles from our searches, as we did not apply a systematic approach, we kept our selection of studies flexible and considered any studies that answered at least one of our research questions. Our intent was to synthesize the literature on nature contact and evaluate its impact of nature on human health during the COVID-19 pandemic rather than exhaustively document all possible studies on these topics. In the sections below, we present a synthesis of the literature we identified organized in areas representing our research questions.

3. Results

3.1. Characteristics of identified studies

Our search in three databases identified 2619 articles (Web of Science: 1223; Scopus: 978; PubMed: 418). After duplicate removal, we identified 1430 articles. Among these, we selected those focused on the following three topics aligned with our research questions: (i) identifying the ways

nature contact has changed during lockdowns (RQ 1 and 2) (e.g., Erdönmez and Atmiş, 2021; Geng et al., 2021; Ugolini et al., 2020, 2021; Venter et al., 2020); (ii) examining the associations between nature contact, mental health, well-being, and COVID-19 transmission/mortality rate (RQ 3) (e.g., Dzhambov et al., 2020; Larson et al., 2021; Liu, 2020; Ribeiro et al., 2021; Russette et al., 2021; You and Pan, 2020); and (iii) exploring how these associations vary by sociodemographic, economic, and racial/ethnic groups (RQ 4) (e.g., Astell-Burt and Feng, 2021; Burnett et al., 2021; Lenaerts et al., 2021; Y. Lu et al., 2021a; Tomasso et al., 2021). The majority of these studies were published from samples in North America, Europe and East Asia, and mostly focused on adult populations. Most studies were also cross-sectional and collected data using online surveys or other secondary sources.

3.2. Changes in nature exposure during the COVID-19 pandemic

3.2.1. Types of exposure

Before COVID-19, nature exposure was generally assessed through three approaches: (i) "cumulative opportunity," describing the amount of natural areas within a spatial unit; (ii) "proximity," representing the distance and access to nearby natural areas; and (iii) "contact," describing direct or indirect interactions with nature in terms amount of time spent or frequency of visiting (Bratman et al., 2019; Frumkin et al., 2017; Holland et al., 2021; White et al., 2020). During COVID-19, studies also adopted these broad categorizations. The cumulative opportunity and proximity-based measures such as nature availability (e.g., percentage green space, satellite-derived vegetation indices), greenness visibility (e.g., window view), and natural area accessibility (e.g., distance to nearest green space) provided opportunities to estimate people's potential for nature exposure during the lockdown. Most of these acted as proxy measures for nature exposure around the home (Holland et al., 2021; Labib et al., 2020, 2021). The duration or frequency of time spent in nature (e.g., in a park, garden) estimated people's indirect or direct contact with nature.

In measuring nature exposure during COVID-19, several studies considered residential neighborhood-based measures of green space availability. The majority of these studies used satellite image derived vegetation indices (e.g., normalized difference vegetation index [NDVI]), land use and land cover datasets (e.g., percentage green space, green space density), or self-reported perceived level of neighborhood greenery (Dzhambov et al., 2020; Klompmaker et al., 2021; Y. Lu et al., 2021a; You and Pan, 2020). Concurrently, studies investigated window view-based greenness exposure to understand the type of nature exposure people may observe from the indoors during lockdowns. These studies usually asked participants to indicate if they had views of nature from their windows (Amerio et al., 2020; Dzhambov et al., 2020; Leon et al., 2020; Marques et al., 2021; Pouso et al., 2021; Soga et al., 2021b). In addition to the availability and visibility of nature, other studies examined access to nature in terms of proximity (measured using walking or Euclidean distances) to publicly available outdoor spaces such as parks, nature reserves, or woodlands (Poortinga et al., 2021; Robinson et al., 2021; Shoari et al., 2020; Ugolini et al., 2020). Several of these exposure measures were considered separately or in combination (Dzhambov et al., 2020; Pearson et al., 2021; Pouso et al., 2021; Ribeiro et al., 2021; Ugolini et al., 2020). All exposure measures indicated the cumulative opportunity of nature exposure or the proximity to publicly accessible green spaces.

While most of the research on nature contact during COVID-19 considered public outdoor nature exposure, some studies examined private gardens and indoor plants. Private gardens were considered as one of the key elements of nature exposure during the COVID-19 (Corley et al., 2021; Lehberger et al., 2021; Marques et al., 2021; Ugolini et al., 2021). This is partly because, during lockdowns, having a private garden provided opportunities to experience nature while staying at home (Corley et al., 2021; Lenaerts et al., 2021; Poortinga et al., 2021). However, a few studies argued that many people might not have had a private garden because they lived in an apartment building, their neighborhood put restrictions on common courtyards, they had a small yard, or were of low socioeconomic status (England, 2020). In these cases, indoor plants may have had the potential to balance the need for nature exposure during lockdowns (Dzhambov et al., 2020; Leon et al., 2020; Spano et al., 2021; Tomasso et al., 2021).

Several studies explored the potential impact of virtual/digital nature contact on human health while staying inside or working as frontline healthcare workers (Elsadek et al., 2021; Houwelingen-Snippe et al., 2020; Olszewska-Guizzo et al., 2021; Putrino et al., 2020; Xu et al., 2021; Zabini et al., 2020). These studies argued that digital nature exposure such as watching nature videos/images, virtual reality (VR) of nature scenes might substitute for real nature for those who have limited access to green spaces or may not have opportunities and enough time to attain real nature contact during the emergency period.

3.2.2. Opportunities for nature exposure

Nature exposure assessment in terms of cumulative opportunity and proximity-based measurements generally acted as a proxy for potential nature exposure, but these measures usually cannot assess the time spent in nature and the intensity of nature exposure (Helbich, 2018; Holland et al., 2021; Labib et al., 2021). For a robust measure of nature exposure in terms of direct or indirect contact during the lockdown period, it is necessary to take account of the frequency, duration, and intensity of nature exposure, in particular the amount of time people spent in natural environments (e.g., in parks, gardens). Correspondingly, several studies investigated how COVID-19 lockdowns modified the frequency of visiting natural areas and the changes in spending time in nature (Table 1). Most of these studies identified that during the lockdown period, frequency of visiting nature and spending time outdoors increased compared to before lockdown (Derks et al., 2020; Grima et al., 2020; Robinson et al., 2021; Venter et al., 2020). However, several studies found that nature contact decreased during the COVID-19 pandemic (Burnett et al., 2021; Curtis et al., 2022; Heo et al., 2021; Ugolini et al., 2021).

Several possible reasons could help explain the contrasting findings regarding nature contact during the COVID-19 lockdown. When and where the data were collected could help explain these differences. For instance, Venter et al. (2020) observed a nearly 300% increase in visit frequency in Norway. They collected the data just after the WHO declared COVID-19 a global pandemic. Therefore, the severity of the lockdown and COVID-19 effects may not have been felt among many residents in their study area.

Table 1
Nature contact during the COVID-19 lockdown compared to before the lockdown.

Study	City/country	Spatial context	Lockdown period in 2020	Baseline period	Dominant change %	Data source
Venter et al. (2020)	Oslo, Norway	City	12 March–31 March	12 to 31 March, 2017-2019	291	Google Mobility & Strava
Derks et al. (2020)	Bonn, Germany	Site	22 March–28 April	April 2019 to February 2020	140	Park visit count
Robinson et al. (2021)	UK	Country	April–July	Before outbreak (no specific date)	72	Primary online survey
Grima et al. (2020)	Vermont, USA	City	28 March–8 June	Before outbreak (no specific date)	69	Primary online survey
Rice and Pan (2021)	Western region, USA	States (region)	April–June	3 January to 6 February, 2020	20	Google Mobility
Lu et al. (2021)	East Asia	Country	9 March–29 March	16 December 2019 to 2 February 2020	5	Instagram posts
Curtis et al. (2022)	USA (620 Counties)	County	March 15–May 9	3 January to 6 February, 2020	−26	Google Mobility
Ugolini et al. (2021)	Italy	Country	31 March–4 May	Before outbreak (no specific date)	−36	Primary online survey
Burnett et al. (2021)	UK	Country	30 April–1 May	Before outbreak (no specific date)	−63	Primary online survey
Heo et al. (2021)	South Korea	Country	21 September–7 December	Before outbreak (no specific date)	−65	Primary online survey

Norway did not observe any major peaks in COVID-19 deaths during their study period, and the number of COVID deaths was lower than the high rates in countries such as Italy (Fig. 1). The effect of higher COVID death rates and strict lockdown on visit frequency was also reflected in Ugolini et al. (2021) and Burnett et al. (2021). Both studies collected data during the first peak in COVID-19 infections and death rates in their respective countries. Understandably, decreased visits to outdoor natural environments may be attributed to the fear of COVID infection, strict lockdown regulations and public park shutdown orders (Khozaei et al., 2021; Larson et al., 2021; Luo et al., 2021; Volenec et al., 2021). Based on this evidence, unsurprisingly, it can be argued that modification of outdoor nature contact during the lockdown was largely attributed to the level of COVID-19 infection and death and the severity of lockdown (Larson et al., 2021; Luo et al., 2021). Additionally, modifications of nature contact during COVID-19 might also be related to the country and cultural contexts (Gelfand et al., 2021). Some countries adhered to social distancing, mask-wearing, and large crowd avoidance more than others (Huynh, 2020; J.G. Lu et al., 2021).

The variations in visit frequency and time spent in nature might also be, to some extent, attributed to how data were collected and other environmental factors such as climate and elevation (Rice and Pan, 2021). Nature contact estimates from "big data" datasets (e.g., Google mobility, Strava, Geotagged Instagram images) did not provide precise definitions of 'natural environments', and may have counted multiple visits by the same individuals. Such data might also not represent the larger population due to inability to obtain data from individuals not using specific apps or not sharing their location information. Almost all the big data studies identified in this review revealed considerable increases in nature contact (Y. Lu et al., 2021b; Rice and Pan, 2021; Venter et al., 2020; Zander S. Venter et al., 2021), whereas smaller datasets (e.g., survey data) utilized by studies in this review reported mixed findings regarding nature contact during COVID-19 (Grima et al., 2020; Heo et al., 2021; Larson et al., 2021; Taff

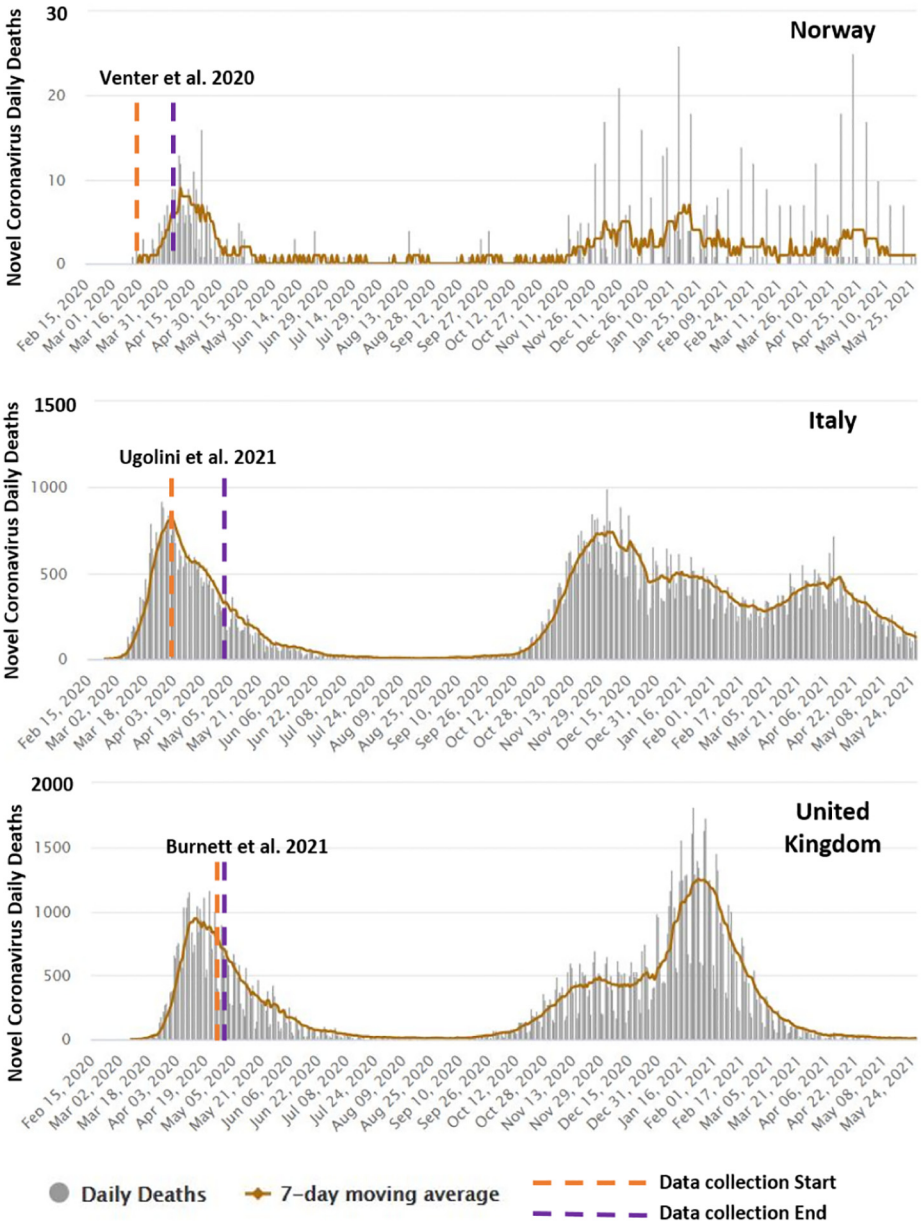

Fig. 1. Coronavirus death rates in Norway, Italy, and United Kingdom, including identified studies that collected data on nature contact in these countries. In Norway, the daily death rates were below, and Venter et al. collected data before the first peak and observed a very high increase in nature visits. In Italy and the UK, daily death rates were between 500 and 1000 when Ugolini et al. and Burnett et al. collected their study data, and both studies observed considerably reduced visits to the outdoor natural environment. Coronavirus death rates data collected from https://www.worldometers.info/coronavirus/.

et al., 2021; Ugolini et al., 2021). Rice and Pan (2021) emphasized the need to validate big data inferred changes in nature visitation. They further argued that changes in visits to the natural environment might be influenced by the difficulty and comfort with being outside as a result of the topographic setting of the study site and seasonal climate conditions. Based on these arguments, it is necessary to consider combining big and small data-based approaches to critically evaluate nature contact modification during the current and future emergencies.

Another important aspect of nature contact modification was the type and location of natural spaces visited by people during the lockdown (Grzyb et al., 2021). Robinson et al. (2021) identified the majority of the surveyed residents (72%) spent on average 40 min longer per nature visit during the lockdown. Among these residents, almost half spent their nature contact time in their private garden (48%). Lehberger et al. (2021) also reported that garden owners spent more time in nature and in their garden specifically during the lockdown than non-garden owners. Ugolini et al. (2020, 2021) identified that the decline in visiting outdoor natural areas was observed most prominently for urban parks under lockdown; meanwhile, visits to smaller gardens near the home (<200 m) increased during lockdowns.

Collectively, these findings indicate that people with access to private green spaces such as gardens had greater nature contact during the pandemic (da Schio et al., 2021; Khalilnezhad et al., 2021; Lenaerts et al., 2021). Additionally, people usually preferred natural areas near their homes and places that were not overcrowded (Berdejo-Espinola et al., 2021; Fischer and Gopal, 2021; Korpilo et al., 2021; Lenaerts et al., 2021; Pearson et al., 2021). In this regard, private gardens acted as a safe green space without the risk of being exposed to the coronavirus while maintaining social distancing guidelines (Marques et al., 2021; Pan et al., 2021; Poortinga et al., 2021; Shoari et al., 2020). Additionally, one study noted that the demand for public green space was higher among people with no private terraces or residential courtyards (Larcher et al., 2021). This evidence also highlights the potential inequities in nature contact during lockdown because a larger share of the socioeconomically deprived population may not have had private or community gardens (England, 2020; Mell and Whitten, 2021). Implications of our findings on environmental and social justice are further discussed in Section 3.4.

Some of the studies on nature contact during the pandemic also explored the underlying reasons for such modifications. Soga et al. (2021a) summarized three possible interrelated pathways based on a behavioral change model from (Michie et al., 2011). These pathways included changes in opportunity (i.e., more free time and abundance of wildlife), capability (i.e., interest in nature and fear toward disease vectors, like bats), and motivation (i.e., changes in mental and physical functioning). We identified several studies that tested these pathways. For instance, studies examined how the opportunity to contact nature may have been modified during lockdown because working from home provided flexible work and discretionary time (Astell-Burt and Feng, 2021; Fagerholm et al., 2021). Astell-Burt and Feng (2021) identified that working from home was associated with increased exercise levels resulting from visits to green/blue spaces. Additionally, the closure of indoor public spaces (e.g., bars, cinemas) increased the demand for outdoor places during people's discretionary time (Soga et al., 2021a). An analysis of Google Search terms found that searches for places to "go for a walk" spiked in March 2020 while searches for places to go shopping or eat out remained more stable (Kleinschroth and Kowarik, 2020). Opportunities for nature contact often depended on the capabilities (physical and mental) of people to seek out contact. Strict stay-at-home regulations limited many people's ability to visit outdoor green spaces but not private (e.g., garden), indoor (e.g., house plant), or virtual spaces (e.g., watching nature videos or VR settings). Additionally, people with mental health conditions may have varying capacity to contact nature (Tester-Jones et al., 2020). People with common mental health disorders were more likely to visit nature compared to people without these disorders. Pfefferbaum and North (2020) pointed out that COVID-19 induced many stressors (e.g., infected family members, economic loss, and preexisting physical or psychological conditions) that may have impacted mental health during and after lockdown periods. Along with changes in mental health, the demand for nature contact might have been modified because people with reduced mental health and wellbeing were seeking refuge in nature.

During COVID-19, both the opportunity and capability for nature contact have been modified; however, the actual contact with nature may have been greatly influenced by personal motivations (Lenaerts et al., 2021; Mateer et al., 2021). Common positive and motivating factors for modified outdoor nature contact during the pandemic included physical exercise, relaxation, taking children outdoors, walking the dog, and meeting friends and family (Bherwani et al., 2021; Dushkova et al., 2021; Erdönmez and Atmiş, 2021; Heo et al., 2021; Luo et al., 2021; Ugolini et al., 2021; Xie et al., 2020). Demotivating factors included crowding, social distance concerns, lack of facilities (e.g., toilets in parks), inability to meet with people outdoors, difficulty accessing safe public green spaces, and governmental policies restricting movement and travel (Luo et al., 2021; O'Brien and Forster, 2021; Shoari et al., 2020). The relative impact of these motivating and demotivating factors is unknown; it can be argued that the lockdown revitalized people's interests in nature and the potential of nature contact to cope with the pandemic (Rousseau and Deschacht, 2020; Z.S. Venter et al., 2021; Volenec et al., 2021).

3.3. Associations between nature exposure and health

Numerous studies investigated associations between nature exposure and mental, physical, and general health, as well as wellbeing during the COVID-19 pandemic. A summary of relations among nature exposure types and various health indicators is presented in Table 2.

3.3.1. Mental health

Nature exposure and mental health associations included evidence that linked nature exposure to reduced depression (Amerio et al., 2020; Dzhambov et al., 2020; Lõhmus et al., 2021; Pouso et al., 2021; Soga et al., 2021b), stress (Cindrich et al., 2021; Gola et al., 2021; Ribeiro et al., 2021), anxiety (Dzhambov et al., 2020; Pouso et al., 2021; Spano et al., 2021; Wortzel et al., 2021), loneliness (Soga et al., 2021b), and increased positive emotions (Khalilnezhad et al., 2021; Lades et al., 2020; Wortzel et al., 2021) and general mental health and wellbeing (Lehberger et al., 2021; Robinson et al., 2021; Stieger et al., 2021). The direction, and consistency of relations varied by types of nature exposure. Views of nature (e.g., through windows) consistently showed stronger associations with lower depression, stress and anxiety level (Pouso et al., 2021; Rajoo et al., 2021; Ribeiro et al., 2021; Soga et al., 2021b; Spano et al., 2021; Wortzel et al., 2021) than neighborhood-level measures of nature accessibility or availability (Cheng et al., 2021; Poortinga et al., 2021). Indoor plants also showed consistent associations with lower depression and anxiety levels (Pérez-Urrestarazu et al., 2021; Spano et al., 2021) (Table 2). Nature contact in terms of increased duration and frequency of outdoor nature visits was associated with increased emotional and mental wellbeing (Browning et al., 2021; Cindrich et al., 2021; Lades et al., 2020; Lehberger et al., 2021; Mayen Huerta and Utomo, 2021).

The presence of a garden, spending time in the garden (for relaxation), and gardening during the pandemic were associated with several mental health outcomes. Multiple studies identified that gardening during the lockdown was directly associated with lower psychopathological distress and indirectly associated through lowering COVID-19 related distress (Sia et al., 2022; Theodorou et al., 2021). Other studies indicated that increased garden usage and gardening activities were associated with improved mental wellbeing, lowered negative emotions, lowered anxiety, and less boredom during lockdown (Corley et al., 2021; Dzhambov et al., 2020; Gola et al., 2021; Lades et al., 2020; Spano et al., 2021). Additionally, Lehberger et al. (2021) identified that garden owners had higher levels of mental wellbeing than non-garden owners.

In addition to actual nature exposure, virtual nature (e.g., digital videos, multisensory nature exposure, virtual reality) was associated with mental health, although the amount of evidence was more limited. Only a few

Table 2
Evidence of the effects of multiple nature exposures on various health-related outcomes.

Health related outcomes	Nature availability* ↑	Nature access ↑	Nature View ↑	Nature Contact** ↑	Garden ↑	Indoor plants ↑	Virtual nature ↑
Depression	●●↓	●↓	●●●↓	●●●↓	●●●↓	●●↓	●↓
Stress	●↓	●↓	●●●↓	●↓	-	●●↓	●↓
Anxiety	●●↓	-	●●●↓	●●↓	●↓	●↓	●↓
Loneliness	-	-	●↓	●↓	-	-	●↓
Psychological wellbeing	●↑	-	-	●●●↑	●●↑	●↑	-
Positive emotions	●↑	●↑	●↑	●↑	●↑	-	-
COVID Cases	●●↓	-	-	●↑	-	-	-
COVID Infection rate	●↑	●↑	-	●↑	-	-	-
COVID death / mortality	●●↓	-	-	-	-	-	-
Physical exercise	●↑	●↑	-	●●↑	●↑	-	-
General physical health	●↑	-	-	-	●↑	-	-
Sleep disturbance	-	-	●●↓	●↓	●↓	●↓	-
Life satisfaction	-	-	●↑	●↑	●↑	-	-
Happiness	●↑	●↑	●●↑	●↑	-	●↑	-

●●● = Protective associations with more consistent supportive evidence, ●● = Generally protective associations but with mixed evidence, ● = Limited evidence for positive associations. Green dots indicate positive associations between the exposure and outcome while red dots indicate the opposite.

* Surrounding/neighborhood natural areas or greenness

** Public outdoor natural space visit frequency and duration

●●● = Protective associations with more consistent supportive evidence, ●● = Generally protective associations but with mixed evidence, ● = Limited evidence for positive associations. Green dots indicate positive associations between the exposure and outcome while red dots indicate the opposite.
∗Surrounding/neighborhood natural areas or greenness.
∗∗Public outdoor natural space visit frequency and duration.

studies explored associations between virtual nature and mental health during COVID-19 (Houwelingen-Snippe et al., 2020; Olszewska-Guizzo et al., 2021; Pearson et al., 2021; Putrino et al., 2020; Zabini et al., 2020). Zabini et al. (2020) showed that watching videos of forested areas for 5 min for five days lowered perceived anxiety levels during lockdown compared to watching videos of urban environments. Similarly, Putrino et al. (2020) observed that 15 min of multisensory simulated nature in a "Recharge Room" reduced stress levels among COVID-19 frontline healthcare workers. Meanwhile, Houwelingen-Snippe et al. (2020) showed that watching digital nature while staying at home due to lockdowns increased nature connectedness and reduced loneliness. This collective evidence suggests that when actual nature exposure (e.g., visiting parks, gardening) was unavailable or limited, virtual nature had the potential to lower the negative psychological impacts of COVID-19 (Elsadek et al., 2021; Olszewska-Guizzo et al., 2021; Pearson et al., 2021). Still, Pearson et al. (2021) noted that real nature was preferred over nature experienced through technology, even during the lockdown. Similarly, a meta-analysis by Browning et al. (2020) found that actual nature exposure might have stronger effects on positive mood states than simulated/virtual nature.

Although a few studies found some associations between nature exposure and mental health outcomes, the magnitudes of the associations were attenuated after adjusting for confounders (Browning et al., 2021; Rodríguez-González et al., 2020; Spano et al., 2021). The studies as a whole suggested that nature exposure during COVID-19 likely had proactive effects in improving mental health conditions..

3.3.2. Wellbeing

A few studies explored if nature exposure was associated with happiness and life satisfaction during the pandemic. These studies reported that although people worried about COVID-19 and its impacts, increased nature exposure was associated with greater happiness, higher subjective wellbeing and life satisfaction (Jackson et al., 2021; Khalilnezhad et al., 2021; Lehberger et al., 2021; Leon et al., 2020; Mayen Huerta and Utomo, 2021; Soga et al., 2021b; Stieger et al., 2021). These findings are in line with pre-pandemic studies that reported living in greener areas was associated with increased happiness and life satisfaction among urban residents and linked with better mental health (Chang et al., 2020; White et al., 2013).

3.3.3. Physical health and health behaviors

3.3.3.1. Physical activity and general physical health. Several studies indicated that increased nature exposure in terms of neighborhood availability, proximity to public natural areas, nature contact (both frequency and duration), and gardening was associated with increased physical activity levels during the pandemic (Table 2). For example, Yang et al. (2021) noted that lockdown caused a reduction in the overall amount of leisure-time physical activity by approximately 4.5 to 5.0 h/week. Still, people who lived in high greenery areas reported a smaller reduction in the overall duration of weekly physical activity (−0.23 min reduction per week, −0.08%) than people who lived in low greenery neighborhoods (−78.84 min reduction per week, −22%). Pombo et al. (2020) noted that during the COVID-19 confinement children with access to outdoor spaces were more active than those without access. Rogers et al. (2020) found that people without garden access engaged in less vigorous physical activities than people with gardens during lockdown. Other studies indicated that the level of physical activity increased with more visits to public green spaces (Astell-Burt and Feng, 2021; Fischer and Gopal, 2021; Ugolini et al., 2021). Interestingly, Lesser and Nienhuis (2020) found people who usually were active (>150 min of physical exercise/week) spent more time each week engaging in outdoor physical activity in nature than less active respondents. Similarly, O'Brien and Forster (2021) noted that less active people (physical activity level ≤ 30 min in the last 7 days) were more likely to reduce their nature contact compared to people with the highest activity levels (≥150 min in the last 7 days). These studies suggest bi-directional interactions between nature exposure and physical activity. On the one hand, nature exposure may encourage physical activity and prevent decreases in pre-COVID physical activity levels. On the other hand, active people may already have had high levels of nature contact. Overall, these findings suggest that nature exposure had positive associations with physical activity level in the midst of the COVID-19 lockdowns.

In addition to physical activity health benefits, nature exposure was positively associated with general physical health during COVID-19. Multiple studies identified that visiting green spaces and increasing garden use during lockdown was associated with improved self-rated physical health (Corley et al., 2021; Li et al., 2021; Xie et al., 2020). This evidence implies that people with higher levels of nature exposure during lockdown may have perceived their physical health to be better than other people regardless of physical activity levels.

3.3.3.2. Sleep. Spano et al. (2021) and Corley et al. (2021) indicated that nature exposure, such as viewing nature through windows and gardening during the lockdowns, was negatively associated with sleep disturbance. This evidence is consistent with a pre-COVID systematic review by Shin et al. (2020), in which the authors reported green space was associated with better sleep quality and quantity. Inadequate sleep and sleep disturbances are considered common risk factors for several mental and physical illnesses (Muscogiuri et al., 2019; Shankar et al., 2010). Based on this evidence, it can be argued that reducing sleep disturbances through nature exposure during the COVID-19 pandemic might have had a critical impact on plummeting both mental and physical health problems.

3.3.4. COVID-19 incidence and mortality

The potential for associations between nature exposure and COVID-related morality, infection rates, and prevalence rates were investigated in several studies. The findings of these studies are somewhat conflicting, indicating both positive-negative relations between nature exposures and COVID-related outcomes. For example, at the early stage of the COVID-19 outbreak using 312 sample cities in China, Liu (2020) identified per capita green space had a negative association with COVID-19 cases, although this finding was not statistically significant. You et al. (2020) studied 13 districts in Wuhan and found that per capita public green space was positively associated with COVID morbidity. Huang et al. (2020) also noted that at the early stage of the outbreak (January to April 2020), higher green space density was associated with more COVID-19 cases for 291 Tertiary Planning Units in Hong Kong. In contrast to these studies, You and Pan (2020) found a 1% increase in green space was associated with 3% less cumulative COVID-19 cases in 989 urban centers in the USA between March and May 2020. Klompmaker et al. (2021) found that higher neighborhood greenness was associated with lower COVID incidence rates among 3089 U.S. counties (6% reduction per 0.1 increase in NDVI), but greenness was not related to COVID mortality at the nationwide level but was in some subgroups. Additionally, Spotswood et al. (2021) observed that a 0.1 increase in NDVI is associated with a 4% decrease in COVID-19 incidence rates for >2600 urban ZIP codes across 17 U.S. states. Several other studies investigated COVID outcomes with residential greenness in counties across the USA and found higher residential greenness associated with reduced COVID-19 mortality (Lee et al., 2021; Y. Lu et al., 2021a; Russette et al., 2021). Similarly, a study in England noted that higher park use is associated with lower COVID incidence within nearly 300 local authorities, although such effects were more pronounced in case of greenspaces that were more connected with one another (i.e., not "patchy") (Johnson et al., 2021).

These conflicting results might be attributed to several reasons such as the stage of COVID-19 wave (e.g., early, peak), location (e.g., near to epicenter, country), variations COVID-19 outcome measures (e.g., number of cases vs. mortality), spatial unit of analysis (e.g., zip code vs. local authority vs. county), metrics to measure nature exposure (e.g., NDVI vs. land use vs. park use), consideration of other built and social environmental factors (e.g., population density, crowding, housing conditions) and lack of consideration for individual-level confounders (Frumkin, 2021; Helbich et al., 2021; Kashem et al., 2021; Russette et al., 2021; You et al., 2020). Several studies extensively investigated the effect of built and social environmental factors on COVID-19 related outcomes (Hu et al., 2021; Huang et al., 2020; Kashem et al., 2021; Nguyen et al., 2020). Among these studies, nature exposure was usually one of several variables within the built environment factors. Some of these studies indicated that built environmental factors such as population density, transport facilities density, crowding ratio, size of the urban area, housing condition, and land use mix might have had stronger associations with COVID-19 transmission rates than residential nature availability and accessibility (Ciupa and Suligowski, 2021; Hu et al., 2021; Huang et al., 2020; Johnson et al., 2021; Nguyen et al., 2020; You et al., 2020). In addition, other studies reported that social factors such as median household income, race/ethnicity, social deprivation and other socioeconomic factors were strong predictors of COVID-19 mortality, morbidity and infection rates (Egede and Walker, 2020; Y. Lu et al., 2021a; Russette et al., 2021). Studies have also linked air pollution (Frontera et al., 2020; Wu et al., 2020), ambient temperature (Bashir et al., 2020; Christophi et al., 2021), and ultraviolet radiation (Isaia et al., 2021) to COVID-19 transmission, incidence, and mortality.

Collectively, COVID-related health outcomes appear to be correlated with complex and numerous socio-ecological and environmental factors, including nature exposure. Some of these factors have been adjusted for in the existing literature on nature exposure and COVID-19 related outcomes, with the positive associations between exposure and favorable outcomes remaining statistically significant after adjustments for these other environmental factors (Hu et al., 2021; Russette et al., 2021; You and Pan, 2020).

A few studies have speculated about the ways that nature accessibility and nature contact (e.g., visit frequency) might relate to COVID-19 transmission and case rates (Pan et al., 2021; Shoari et al., 2020; Wynveen et al., 2021; You et al., 2020). Pan et al. (2021) identified that higher nature accessibility in connected public parks was associated with a higher risk of COVID-19 infection rate in London boroughs. They also noted that larger green spaces had higher levels of accessibility and attracted more visitors, which may have resulted in less strict adherence to social/physical distancing regulations and greater transmission. Similarly, Shoari et al. (2020) argued that parks in England might not have enough space to maintain proper social distancing during high levels of park visitation in densely populated areas, and this might have hindered the social distancing requirements necessary to prevent coronavirus transmission. Similar observations of higher park visits and increased COVID-19 cases were observed by some studies (Y. Lu et al., 2021b; You et al., 2020). These authors argued that during

the early stage of the pandemic, people were allowed to visit green spaces without strict physical distancing guidelines. These visitors may not have maintained proper distancing during the visits and therefore increased transmission rates (Y. Lu et al., 2021b; Pan et al., 2021; Wynveen et al., 2021). In contrast, a few studies observed that increased park visits did not correspond to higher COVID-19 incidence (Curtis et al., 2022; Johnson et al., 2021; Zander S. Venter et al., 2021). The results of these studies need to be considered carefully because all of them used aggregated mobility data from Google and other providers along with an ecological modeling approach. Both of these limitations may not accurately translate to individual-level results or reflect actual scenarios at micro-scales, especially in contrast to the earlier studies that investigated transmission patterns at finer-resolutions (Pan et al., 2021; You et al., 2020).

3.4. Variations in nature contact changes and nature-health associations by sociodemographic, economic, and racial/ethnic groups

We identified several studies that examined how associations between nature exposure and health during the COVID-19 pandemic varied by socioeconomic status (SES). One of these showed that lower-SES groups benefited more from nature exposure than higher-SES groups in regard to mental health (Burnett et al., 2021). Some studies reported mixed findings or no difference between SES groups in regard to the health correlates of nature exposure they tested. Survey data from a nationally representative sample of Australians in October 2020 indicated that people who reported more difficult financial situations spent less time in natural environments and felt less that these spaces helped them socially connect more than people with better financial situations. However, no differences in the extent to which natural environments offered solace and respite were observed between income, educational achievement, or self-reported financial situation levels (Astell-Burt and Feng, 2021). Another study in four U.S. metropolitan areas found no difference in the predictive power of nature deprivation during lockdown to explain psychological wellbeing across neighborhood income levels (Tomasso et al., 2021). No differences between socioeconomic groups were observed in associations between nature exposure and somatization (i.e., pain, fatigue, headaches) or psychological distress during lockdown in survey respondents living in Spain and Portugal (Ribeiro et al., 2021). In contrast, a second UK survey in April to May 2020 found that lower social class respondents (i.e., laborers) visited green space less during the lockdown, decreased their green space visitation rates more during lockdown compared to before lockdown, and felt less that green space benefited their mental health than higher class respondents (i.e., managers) (Burnett et al., 2021). Findings for COVID-related outcomes were also mixed. Klompmaker et al. (2021) examined effect modification by area-level income and reported that the protective association of green space on COVID-19 incidence was stronger for U.S. counties with higher median household incomes than other counties, yet no differences by income were found for COVID-19 mortality rates. Spotswood et al. (2021) observed differences in nature exposure and COVID-19 outcomes among different income groups at the U.S. block level and noted that communities most impacted by COVID-19 also had the least nature exposure.

Several of these same studies also tested for differences in nature exposure and associations with health by gender/sex, finding no major differences in most analyses. The Australian survey mentioned above found that men spent less time in natural areas during lockdown compared to women (Astell-Burt and Feng, 2021). Despite spending less time in nature, men indicated that natural areas provided greater solace, respite, and feelings of social connection compared to women counterparts (Astell-Burt and Feng, 2021). The April 2020 U.K. survey found the opposite. Women reported that green space benefited their health more during the lockdown than before the lockdown relative to men (Burnett et al., 2021). Women also decreased their green space visitation frequency during lockdown compared to before the lockdown more than men, yet no differences in total green space visitation rates and durations were found between men and women. Essentially no sex/gender differences were found in associations between public green space proximity and well-being or general health in a U.K. study administered in March/April and then again in June to July 2020 (Poortinga et al., 2021). However, the U.K. study authors observed that having a private garden was associated with higher levels of well-being in men than in women. Additionally, one study in Iran noted during the pandemic women missed visiting green spaces more than men (Khalilnezhad et al., 2021).

A few studies have examined the potential for differential use or effects of green space among certain racial/ethnic groups. In the U.S., feeling nature-deprived during the pandemic was associated with psychological well-being by race (Tomasso et al., 2021). Specifically, White people who felt nature-deprived had lower levels of psychological well-being, whereas racial/ethnic minority people who felt nature-deprived had higher levels of psychological well-being (Tomasso et al., 2021). U.S. counties with greater shares of Black residents showed no differences in associations between green space and COVID-19 incidence than counties with lower shares of Black residents; further, counties with the smallest shares of Black residents showed positive associations between green space and COVID-related mortality (Klompmaker et al., 2021). A second study restricted to the most urbanized U.S. counties found related findings; green land coverage reduced racial/ethnic disparities in COVID-19 infection rates between Black and White people (Y. Lu et al., 2021a).

4. Discussion

4.1. Summary and interpretation of main findings

In this literature review, we synthesized research carried out during COVID-19, which has explored the role of nature exposure on public health at varying stages of lockdowns. Based on the collective evidence observed among studies, the overall changes in nature exposure and related health effects are summarized in Fig. 2. Except for access to public natural spaces such as urban parks during COVID-19 lockdown, opportunities for nature exposure have generally increased. The lockdown situation acted as a determinant of people's opportunity (e.g., reduced visits to public parks due to movement restrictions), capacity, motivation, perception for nature contact (Larcher et al., 2021; Volenec et al., 2021) (more in Section 3.2.2). Some exposure types witnessed greater changes than others, such as reporting of increased green view through windows; additionally, gardening increased when staying at home. However, the frequency of visiting outdoor natural spaces had mixed changes depending on lockdown severity, sociocultural contexts, and personal motivation factors (details in Section 3.2.2).

The changes in nature exposure during the pandemic were associated with several health-related outcomes. These associations were generally in the positive direction, indicating that increased nature exposure during COVID-19 generally improved health and wellbeing and that nature exposure showed protective effects in coping with mental and physical health conditions. As presented in Fig. 2, for mental health, studies showed consistent positive associations between all types of nature exposures and lower depression, anxiety, stress as well as improved wellbeing (e.g., happiness, life satisfaction) (more in Section 3.3.1). Studies also indicated evidence in favor of the positive influence of gardening and garden ownership on improved mental health. In pre-COVID studies, gardening and garden ownership were reported to improve mental health conditions (Bell et al., 2020; Chalmin-Pui et al., 2021; Soga et al., 2017). Considering the strong evidence of the positive effects of gardens in pre-COVID and COVID period studies, it can be argued that private green spaces such as gardens provided considerable mental health benefits during COVID-19 pandemic, especially under lockdowns.

Based on the available evidence, we argue that nature played a vital role in lowering mental health burden during COVID-19 pandemic. The potential positive effects of nature exposure in improving mental health conditions are supported by widely recognized stress reduction (Ulrich, 1984; Ulrich et al., 1991) and attention restoration theories (Kaplan and Kaplan, 1989; Kaplan, 1995). Both theories posit that nature exposure could improve mental health through expediting the recovery from stress, improving cognitive functioning, and attention restoration. These theories appear to remain viable and salient during COVID-19. As the lockdown

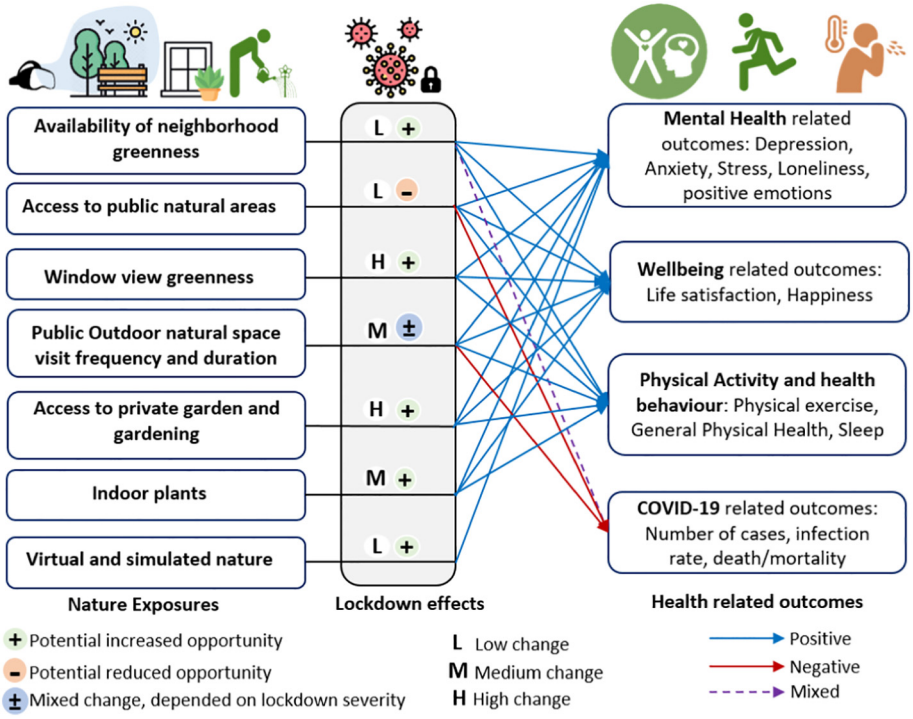

Fig. 2. Nature exposure types, COVID-19 lockdown effect on exposure (e.g., changes in opportunities), and nature exposure associations with health-related outcomes. The blue arrows indicate dominant positive, the red arrows indicate dominant-negative, and the dotted arrow indicates mixed associations of nature exposure with health-related outcomes.

period induced stress and anxiety among the population, nature exposure may have buffered these adverse outcomes and prevented deteriorating mental health conditions.

Nature exposure and physical health relations during the COVID-19 pandemic mainly investigated two domains. One focused on the impact of nature exposure on levels of physical activity, general physical health, and health behavior. The other domain explored associations between nature exposure and COVID-19 related health indicators (e.g., mortality, infection rate). In the first domain, nature exposure might have been associated with lowering physical inactivity during COVID-19 and thus physical health benefits for COVID-19 patients. Multiple studies noted that physically-inactive COVID-19 patients were more vulnerable to critical health conditions during and after the acute infection period (Després, 2021; Sallis et al., 2021). Such evidence could be extended to suggest that the potential protective influence of nature exposure through building the capacity for health (e.g., encouraging physical exercise) (Markevych et al., 2017; Nieuwenhuijsen et al., 2017; Remme et al., 2021) may have reduced the risk of severe outcomes, including mortality related to COVID-19 infection. This is because the reduction in physical activity resulting from lockdowns may increase the risks associated with COVID-19 mortality, obesity, cardiovascular diseases, diabetes, and other non-communicable diseases (Kluge et al., 2020; Sallis et al., 2021). Interestingly, one study found that among the COVID-19 patients over 45 years, people with higher residential greenness were significantly associated with lower COVID-19 severity (Peng et al., 2022). In the second domain, the potential for associations between nature exposure and COVID-related morality, infection rates, and prevalence rates have been investigated in several studies (see Section 3.3.3). These studies indicated that some nature exposure types showed mixed and negative associations with COVID-19 related outcomes (Fig. 2), such as increased access and visitation to outdoor green spaces, which may have been associated with increased COVID-19 infection rates.

These two domains of studies indicated mixed effects of nature exposure on physical health conditions during the lockdown. Nature exposure may have encouraged physical activity and prevented increase in physical inactivity. Such a phenomenon may have aided in preventing the deterioration of physical health conditions and reduced the non-communicable disease burden throughout the pandemic. Simultaneously, nature exposure might have impacted COVID-19 incidence and mortality rates as a result of non-strict adherence to social distancing regulations (Wynveen et al., 2021) and increased coronavirus transmission. These phenomena likely depended on several factors such as the size of public parks, the number of people visiting, types of activities (e.g., meeting others), and opportunities to maintain social distancing (Pan et al., 2021; Shoari et al., 2020). Nonetheless, the overall benefit of nature exposure on maintaining physical activity might be more extensive than susceptibility of coronavirus transmission, since a few studies have reported that the risk of COVID-19 and other respiratory viruses transmission is usually lower in outdoor settings if physical distancing is maintained (Bulfone et al., 2021; Dominski and Brandt, 2020; Rowe et al., 2021). Further research is warranted to fully understand the overall effects of nature exposure on physical health outcomes over the period of COVID-19 pandemic.

A few studies explored the equity dimension to nature exposure and health, and they examined whether income, sex/gender, or race/ethnicity modify the nature-health associations during lockdowns report disparate findings, and in most cases, no considerable effect modification. These findings are likely due to the small sample size of articles to date, heterogeneity in sample characteristics, and measurement differences (i.e., respondent's self-reported social class vs. median household income in the case of SES). The mixed nature of these findings somewhat represents the green space-health literature more broadly (Bolte et al., 2019; Kabisch, 2019; Rigolon et al., 2021). As a whole, the current evidence does not confirm or deny the possibility that nature exposure increased or decreased health inequities during the COVID-19 pandemic. More studies could deliberately consider health equity when studying associations between nature exposure and health during similar emergencies.

4.2. Policy and practice directions

The available evidence overwhelmingly supports the conclusion that nature exposure was associated with better mental and behavioral health

during COVID-19. However, because the majority of the studies were cross-sectional in design, causal relations cannot be confirmed. Considering the consistency of positive associations between nature exposure and health from longitudinal studies (pre-COVID vs. during-COVID), we argue that, if these associations are causal, nature exposure has the potential to maintain or even improve public health outcomes during the ongoing pandemic, aid in recovery from the negative impacts of COVID-19, and increase resilience to future crises. In conjunction with United Nations Sustainable Development Goals such as Good Health and Wellbeing (SDG-3) and Sustainable Cities and Communities (SDG-11), we recommend several nature-based policies and practice directions to increase nature exposure for health and wellbeing (Fig. 3).

4.2.1. Nature-based infrastructure (NB-Inf)

NB-Inf is an emerging concept that indicates a range of ecosystem-based approaches that address societal challenges (e.g., human health, climate change) by providing both human well-being and ecosystem benefits. NB-Inf elements are drawn from the broader concepts of nature-based solutions addressing societal challenges using ecosystem approaches (Cohen-Shacham et al., 2016, 2019). Among various ecosystem-based approaches within nature-based solutions, green infrastructure (GI), renaturing, and forest landscape restoration focusing on urban greening (UG) are crucial nature-based infrastructure domains to maintain and improve cities' health and well-being during crises like the COVID-19 pandemic. Both of these approaches have the potential to augment cumulative opportunities for nature exposure and address health-related societal challenges in the context of crises such as pandemics and climate change (Bayulken et al., 2020; Escobedo et al., 2019; Kabisch et al., 2017; Nieuwenhuijsen, 2021; Tzoulas et al., 2007).

Several elements of GI and UG could contribute to short-term COVID-19 recovery and long-term resilience for health and wellbeing in response to future emergencies (Fig. 3). For short-term recovery, some GI elements such as green walls, pocket parks or parklets, and community gardens could play vital roles in increasing opportunities for nature exposure within residential neighborhoods. In particular, green walls, pocket parks, parklets, and small community gardens could be developed within a relatively short period compared to GI and UG elements such as planting street trees, creating amenity green spaces, and urban parks. It should be noted, during COVID-19 lockdowns, in several cities, parking lots were being converted into parklets (e.g., Birmingham, England; San Francisco, CA), and small pocket parks and gardens being created (Hanzl, 2020). Converting parking spaces into parklets and greening vacant lots into pocket parks and gardens could help deliver multiple health benefits within a shorter timeline and reduce the pressure from larger urban parks hence lowering the risk of transmission due to overcrowding (Hanzl, 2020; Liu and Wang, 2021; Pan et al., 2021; Sivak et al., 2021). When designing these spaces, care should be taken to ensure they provide opportunities to maintain adequate physical distancing through innovative spatial configuration and arrangements of landscape furniture (e.g., public benches) to limit virus transmission (Hassan and Megahed, 2021).

For longer-term resilience, other GI and UG elements (e.g., urban parks, woodlands) can be implemented through spatial and urban planning strategies at multiple spatial scales (e.g., neighborhood, city) (Dushkova et al., 2021; Mell, 2021). In this regard, the Nature Based Solutions Institute recently introduced a new rule of thumb for urban forestry and urban greening: the 3-30-300 rule (Bosch, 2021). According to this rule, "*Everybody should be able to see 3 trees from their home, live in a neighborhood with at least 30% tree canopy (or vegetation) cover, and be no more than 300 m from the nearest green space that allows for multiple recreational activities*" (https://nbsi.eu/). This rule may assist in developing long-term GI and UG planning to achieve improved health and wellbeing of each individual even during crises like COVID-19. As a whole, we recommend that NB-Inf should be integrated into the further planning and policies to rebuild cities and communities to ensure greater opportunities for nature exposure to improve or maintain health and wellbeing during emergencies.

4.2.2. Nature-based interventions (NBI)

Although NB-Inf can increase the cumulative opportunities for nature exposure, the health benefits of nature exposure are also correlated with the duration and frequency of nature contact (Bratman et al., 2019; Holland et al., 2021). To be more certain about obtaining health benefits from nature exposure, a wealth of existing literature suggests adopting and implementing nature-based interventions (Garside et al., 2021; Wilkie and Davinson, 2021). Nature-based interventions differ from NB-Inf in the former's focus on people and their behavior regarding intentional nature contact through interventions broadly grouped under green care and eco-therapy (Harper et al., 2021; Shanahan et al., 2019). Fig. 3 illustrates some vital interventions under these broader groups. Green exercise, park prescription, social and therapeutic horticulture, forest bathing are commonly used interventions to increase nature contact (Chaudhury and Banerjee, 2020; Kotera et al., 2020; Muro et al., 2022; Rajoo et al., 2021; Wilkie and Davinson, 2021). COVID-19 lockdowns have resulted in severe mental health crises, including an increased prevalence of post-traumatic stress disorder (PTSD) (Salehi et al., 2021). Chaudhury and Banerjee (2020) argued that certain NBI such as green exercise and social and therapeutic horticulture has great potential to mitigate PTSD, depression, stress, and other mental health-related issues associated with COVID-19. Additionally, Rajoo et al. (2021) noted that nature therapy was more effective in treating mental health issues during COVID-19 than nature exercise only.

Based on these observations, we recommend developing and implementing NBI to mitigate the negative impacts of COVID-19 on mental health. Nature contact and connectedness induced by NBI may increase overall wellbeing and promote pro-environmental behavior (Bosch and Sang, 2017; Martin et al., 2020). These collateral effects may ensure long-term recovery from COVID-19 and increase consciousness among people about the value of the natural environment and the ways humans should care about the ecosystem health for their survival. Care should be taken in designing NBI during lockdown situations so that the interventions do not increase the risk of virus transmission by bringing many people together. In such regard, virtual nature therapy might also be an effective alternative when actual nature contact cannot be arranged (White et al., 2013; Yeo et al., 2020).

4.2.3. Nature-based design (NBD)

COVID-19 lockdowns have demonstrated the need for both indoor and outdoor nature exposures for mental and physical health. To ensure a variety of nature exposures while staying indoor during lockdowns, working from home, and overall living in nature, we recommend adoption and implementation of nature-based design principles such as biophilic design for both indoor and outdoor space design (Kellert, 2018; Kellert et al., 2011; Ryan et al., 2014). Kellert (2018) noted that biophilic design principles focus on buildings and constructed landscapes that foster human health through increased contact with the natural world. Ryan et al. (2014) presented three categories (i.e., nature in the space, natural analogs, and nature of the space) and fourteen patterns of biophilic design (e.g., visual connection, presence of water; Fig. 3) that may reflect nature-health relationships in varying built environment contexts. In particular, visual connection with nature should be considered as a critical design principle for buildings.

Non-visual connections (e.g., auditory) should also be carefully considered in designing buildings and outdoor spaces. Such as, priority should be given to maximizing natural sounds over urban sounds (Browning et al., 2014). In this regard, two studies identified that during COVID-19, people with higher mental stress obtained a greater mental restoration through water sounds compared to pre-COVID samples (Qiu et al., 2021; Qiu and Zhang, 2021). Design patterns such as prospect and refuge, biomorphic forms should also be integrated into urban design to increase overall nature connections through multisensory experience of nature as part of everyday life (Browning et al., 2014; Kellert et al., 2011; Ryan et al., 2014). It should be noted that 'Biophilic cities' (https://www.biophiliccities.org/), a global

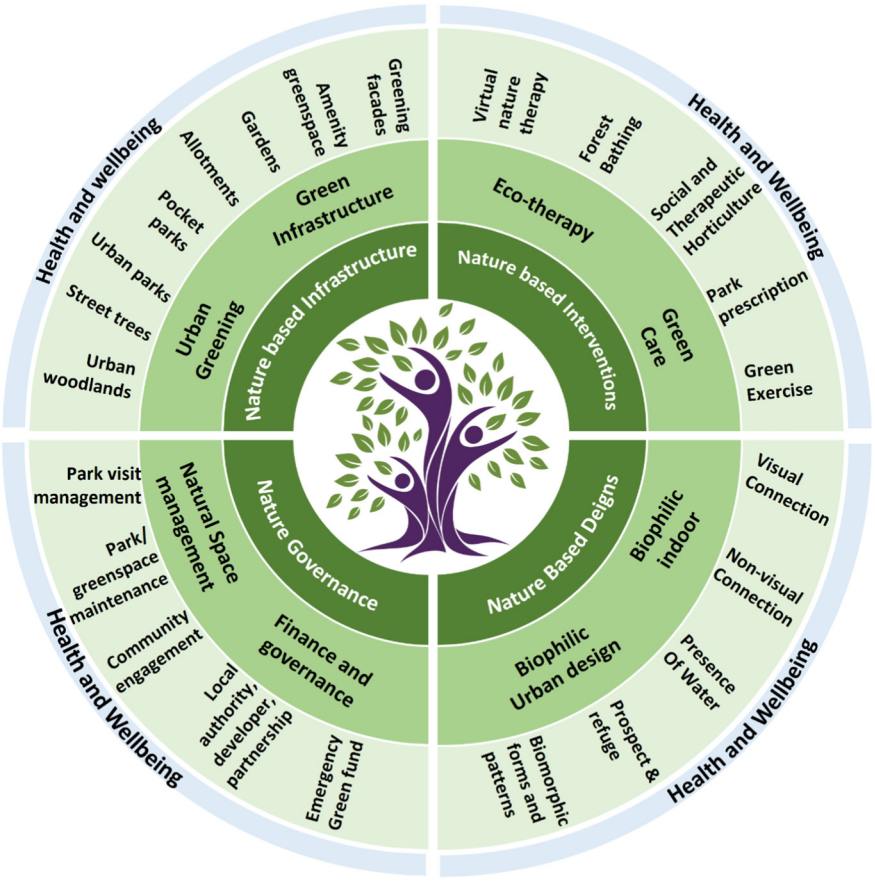

Fig. 3. Nature-based policies and practice dimensions to increase nature exposure through nature-based infrastructure, interventions, design, and governance. Each thematic area provides examples of broad and specific policies and practice elements at multiple levels to ensure nature exposure contributes during the ongoing pandemic, the recovery phase of the COVID-19, and aids in maintaining human health and wellbeing in the future for similar or other health-related emergencies.

network including 24 partner cities (e.g., Edinburgh, Barcelona, Washington, DC, Willington) currently promoting biophilic urban designs along with NBS to increase nature exposure in urban settings. Such initiatives should be extensively adopted and replicated in other cities worldwide.

4.2.4. Nature governance

To ensure nature exposure benefits public health in times of emergencies such as COVID-19, it is necessary to develop governance strategies focusing on outdoor natural space management and financial mechanisms to support NB-Inf and NBI. In terms of management and maintenance of public natural spaces, park or green space managers should consider the number of people visiting the parks and maintenance of the facilities to support visitors (Fig. 3). Notably, in case of virus-related emergencies when social distancing is crucial to restrict the transmission, park managers may consider adopting measures such as dedicated park times for various age groups, entry allocation systems to ensure the numbers of people visiting the parks can maintain adequate social/physical distancing (Moore and Hopkins, 2021; Shoari et al., 2020). Additionally, managers should also focus on maintaining the park facilities, such as keeping the toilets open and clean and regularly clearing the litter.

Financial and governance support to implement NB-Inf, NBI, and NBD are often challenging due to monetary constraints, lack of awareness, and inadequate leadership (Garside et al., 2021; Kabisch, 2015; Mell, 2021). In order to adopt and implement nature-based policies and practices that benefit health and wellbeing in a post-COVID world, it is necessary to ensure adequate funds, community engagement, and multi-stakeholder participation (Fig. 3). We recommend creating partnerships between local authorities, developers, designers, and community groups when implementing NB-Inf and NBD in new developments (e.g., housing) and retrofitting existing neighborhoods. Care should be taken in implementing NB-Inf in areas such as historically disinvested neighborhoods because developing new green spaces in such areas may result in green gentrification (Rigolon and Németh, 2020; Triguero-Mas et al., 2021; Wolch et al., 2014) and the displacement of low-income residents for whom the NB-Inf strategies were designed to benefit (Cole et al., 2017; Triguero-Mas et al., 2021; Wolch et al., 2014). Funds to support NB-Inf, NBI, and NBD may be available through government infrastructure investment as part of the post-COVID recovery and creation of emergency 'green funds' from multiple stakeholders, including local authorities, developers, business (e.g., corporate social responsibility), and communities (Frumkin, 2021; Mell, 2021; Mell and Whitten, 2021).

5. Conclusion

We synthesized the evidence of nature's role in coping with the COVID-19 pandemic focusing on the relations between nature exposure and human health during the first two years of the pandemic. During 2020 and 2021, various nature exposure types were observed and studied. Numerous researchers investigated outdoor (e.g., residential greenness, park access), indoor (e.g., plants), and simulated (e.g., virtual reality) nature exposure and their associations with health, wellbeing, and COVID-related outcomes. Our review suggests several critical roles of nature exposure during the pandemic:

- During COVID-19, many people increased their contact with nature. Spending time in private green spaces such as gardens considerably increased, along with increased visits to select outdoor natural areas. The

duration and frequency of visits to public natural areas were influenced by the severity of lockdowns, COVID-19 mortality rates, and socio-cultural factors.

- Nature exposure during the COVID-19 pandemic was consistently associated with improved mental health and wellbeing (strong evidence). Increased nature exposure was related to less depression, stress, loneliness, and anxiety. Nature exposure was also related to less physical inactivity and fewer sleep disturbances. Some studies found mixed evidence regarding associations between nature exposure and COVID-related health outcomes such as mortality and incidence rate, while others suggested that visits to urban green spaces might have increased the risk of COVID-19 transmission when visitors did not comply with public health guidance (i.e., maintaining social distance and/or wearing a face mask). Still, several studies noted that visiting natural outdoor spaces had a relatively low risk of COVID-19 transmission compared to indoor areas and other public spaces.
- Evidence was mixed regarding the modifying effects of age, gender, socio-economic status, and race/ethnicity on nature-health relationships during the COVID-19 pandemic.

In summary, nature exposure played an essential role during the COVID-19 pandemic. Specifically, nature exposure may have prevented further mental and physical health deterioration on a large scale. These findings should be interpreted in light of the heterogeneous mix of studies using primarily cross-sectional data from diverse populations and contexts. Nonetheless, considering the consistency of the positive associations between nature exposure and health outcomes, we argue that recovery and resilience during current and future public health crises might be strengthened by nature-based infrastructure, interventions, biophilic designs, and governance strategies and practices.

CRediT authorship contribution statement

S.M. Labib: Conceptualization, Methodology, Data curation, Data synthesis, Writing – original draft, Visualization, Writing – Review & Editing. **Matthew H.E.M. Browning**: Conceptualization, Methodology, Writing – review & editing. **Alessandro Rigolon**: Conceptualization, Methodology, Writing – review & editing. **Marco Helbich**: Conceptualization, Methodology, Writing – review & editing. **Peter James**: Conceptualization, Methodology, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Search strings

Pubmed: *(Greenspace[Title/Abstract] OR Greenness[Title/Abstract] OR Green space[Title/Abstract] OR Outdoor[Title/Abstract] OR greenery[Title/Abstract] OR Blue space[Title/Abstract] OR Park[Title/Abstract]) AND (COVID [Title/Abstract] OR COVID-19[Title/Abstract] OR Coronavirus[Title/Abstract] OR Pandemic[Title/Abstract]) AND ((fft[Filter]) AND (2020/3/1:2021/4/30 [pdat])) AND ((fft[Filter]) AND (2020/3/1:2021/12/31[pdat]))*; **Results = 418**.

Scopus: *TITLE-ABS-KEY (Greenpeace OR (green AND space) OR Greenness OR Outdoor OR Greenery OR (Blue AND Space) OR Park) AND TITLE-ABS-KEY (COVID OR COVID-19 OR Coronavirus OR Pandemic) AND PUBDATETXT ("March 2020" OR "April 2020" OR "May 2020" OR "June 2020" OR "July 2020" OR "August 2020" OR "September 2020" OR "October 2020" OR "November 2020" OR "December 2020" OR "January 2021" OR "February 2021" OR "March 2021" OR "April 2021" OR "May 2021" OR "June 2021" OR "July 2021" OR "August 2021" OR "September 2021" OR "October 2021" OR "November 2021" OR "December 2021") AND (LIMIT-TO (LANGUAGE,"English"))*; **Results = 978**.

WOS: *(TS = (Greenspace OR Green space OR Greenness OR Outdoor OR Greenery OR Blue Space OR Park) AND TS = (COVID OR COVID-19 OR Coronavirus OR Pandemic)) AND (DOP = (2020-03-01/2021-12-30)) AND LA = (English)*; **Results = 1223**.

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