

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

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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 year of the COVID-19 pandemic. We found that during lockdowns, 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 lockdowns 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, for example, impacting the health of lower-socioeconomic populations more than their higher-socioeconomic counterparts, were mixed. Based on these findings, we argue that nature exposure may have buffered the negative mental and behavioral impacts of lockdowns during the first year of the COVID-19 pandemic. Recovery and resilience during the current and future public health crises might be improved with nature-based solutions, interventions, designs, and governance.

Key words: Greenspace, Blue space, Plants, Greenness, Nature exposure, Health, COVID-19, Coronavirus pandemic, Nature-based solutions, Nature-based interventions

1. Introduction

On 11 March 2020, the World Health Organization declared the coronavirus outbreak a pandemic, and in August 2021, we entered the 17th 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). And as of August 2021, the COVID-19 pandemic continues to rage in many countries due to the highly contagious delta variant and other variants of concern (Katella, 2021; Lopez Bernal et al., 2021). To contain the spread of the infection and minimize strain on health services, governments worldwide imposed restrictions such as lockdowns or other social and physical distancing measures in the early phases of the pandemic (Atalan, 2020; Meyer et al., 2020), and lockdowns and other measures are still in place in August 2021 in many countries (BBC News, 2021). Several studies have documented that lockdown measures may have reduced the spread of the infection, thus saving millions of lives (Flaxman et al., 2020; Brauner et al., 2021).

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 human health (Pfefferbaum and North, 2020; Brooks et al., 2020; D'alessandro et al., 2020; Lippi et al., 2020). Notably, the 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 (Mattioli et al., 2020; Pal & Bhadada, 2020; Ledford et al., 2021; Lades et al., 2020). There are numerous reasons for the negative impact of lockdowns on physical and mental health; some 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; Peçanha et al., 2020; Ledford et al., 2021). 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 (Pouso et al., 2021; Mayen Huerta and Cafagna, 2021; Yang et al., 2021; Ribeiro et al., 2021).

Numerous reviews have documented the evidence of the potential influence of exposure to the natural environment on human health and wellbeing (White et al., 2020; Rojas-Rueda et al., 2019; Bratman et al., 2019; Twohig-Bennett and Jones, 2018; Frumkin et al., 2017; Van den Bosch and Sang, 2017; Gascon et al., 2015; Hartig et al., 2014), along multiple mechanistic pathways (Marselle et al., 2021; Markevych et al., 2017; Nieuwenhuijsen et al., 2017; Hartig, 2021). In general, these studies reported that nature exposure have positive health effects by mitigating health stressors (e.g., heat reduction), increasing restoration such as stress recovery, and building capacity by encouraging physical

activities (Markevych et al., 2017; Van den Bosch and Sang, 2017; Kondo et al., 2018; James et al., 2015). However, studies have also reported some negative health effects of nature contact, notably through increased exposure to allergens, infectious diseases, and harmful microbiota (Marselle et al., 2021; Aerts et al., 2018). It should be noted that the evidence of the effects of exposure to nature on human health are primarily documented on pre-COVID studies between 2000-2020. These reviews indicated strong evidence for net positive effects of nature exposure on human health and wellbeing (Van den Bosch and Sang, 2017; Twohig-Bennett and Jones, 2018; Jimenez et al., 2021). 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 lockdown within the first year of the pandemic (March 2020 - April 2021).

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 across 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; 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; 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 & 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).

Nature exposure has been identified as a possible environmental factor that could reduce health disparities (for review, see 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; Marmot et al., 2008; Markevych et al., 2017; 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).

Among the nature exposure and health studies published during the first year of 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 (Sapano et al., 2021; Pan et al., 2021; Browning et al., 2021; Corley et al., 2021; Lu et al., 2021a). Considering these variations in evidence among the existing studies, it seems timely and reasonable to review the net contributions of nature in coping with the pandemic. 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. Considering the mounting number of studies in this timely field of study, we aim to synthesize the evidence for nature contact during the first year of the COVID-19 pandemic and its consequences on human health. Specifically, we investigate the following four 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 (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). 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 synthesising 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) COVID-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 30th April 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. Our intent was to synthesize the literature on nature contact and evaluate its impact of nature on human health during the first year of 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 1,220 articles (Web of Science: 433; Scopus: 414; PubMed: 373). After duplicate removal we identified 688 articles. Among these studies, we selected those focused on following three topics aligned with our research objectives: (i) identifying the ways nature contact has changed during lockdowns (e.g., Geng et al., 2021; Venter et al., 2020; 2021; Ugolini et al., 2020; 2021); (ii) examining the associations between nature contact, mental health, well-being, and COVID-19 transmission/mortality rate (e.g., Ribeiro et al., 2021; Dzhambov et al., 2020; Liu, 2020; You and Pan, 2020; Russette et al., 2021); and (iii) exploring how these associations vary by sociodemographic, economic, and racial/ethnic groups (e.g., Lu et al., 2021; Burnett et al., 2021; Astell-Burt and Feng, 2021; 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. Additionally, most of these studies were cross-sectional in study design, and collected data using online surveys, and 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 (Bartman et al., 2019; Furkmin et al., 2017; White et al., 2020; Holland et al., 2021). During COVID-19, the studies identified in this narrative review 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; Lu et al., 2021a; You and Pan, 2020; Klompmaker et al., 2021). Concurrently, studies also 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 (Dzhambov et al., 2020; Soga et al., 2020; Pouso et al., 2021; Amerio et al., 2020; Leon et al., 2020). 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; Shoari et al., 2020; Ugolini et al., 2020; Robinson et al., 2021). Several of these exposure measures were considered separately or in combination (Dzhambov et al., 2020; Ugolini et al., 2021; Pouso et al., 2021). 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 exposures, some studies also examined private gardens and indoor plants. In particular, private gardens have been considered as one of the key elements of nature exposure during the COVID-19 lockdown (Lehberger et al., 2021; Corley 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; Poortinga et al., 2021). However, a few studies argued that many people might not have had a private garden because they live in apartment buildings, their neighborhood puts restrictions on common courtyards, have a small yard, or are of low socioeconomic status (Natural England, 2020). In these cases, indoor plants may have had the potential to balance the need for nature exposure during lockdowns (Leon et al., 2020; Sapano et al., 2021; Tomasso et al., 2021; Dzhambov et al., 2020). In addition, a few studies explored the potential impact of virtual/digital nature contact on human health while staying inside or working as frontline healthcare workers (van Houwelingen-Snippe et al., 2020; Putrino et al., 2020; Zabini et al., 2020). These studies argued that digital nature exposure might substitute for real nature for those who have limited access to green spaces or may not have opportunities and enough time to attain actual 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 (Holland et al., 2021; Labib et al., 2021; 2020; Helbich, 2018). 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, the frequency of visiting nature and spending time outdoors increased compared to before lockdown. However, one-in-three studies found that nature contact decreased during the lockdown (Ugolini et al., 2021; Burnett et al., 2021; Heo et al., 2021).

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

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

There may be several reasons for the contrasting findings regarding nature contact during the COVID-19 lockdown. A key difference between the available literature is when and where the data were collected. 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. 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 (**Figure 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 and strict lockdown regulations (Khozaei 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, as well as the severity of lockdown. Additionally modifications of nature contact during COVID-19 might also be related to cultural factors, such as cultural tightness-looseness (Gelfand et al., 2021). For instance, Scandinavian countries like Norway, have tighter cultures with a strong sense and adherence to order and customs while looser countries like the UK and Italy have cultures with less order and coordination, which may be tied to adherence to social distancing, mask wearing, and large crowd avoiding (Gelfand et al., 2021). Our observations might also be explained by tighter countries like Norway seeing lower levels of COVID-19 infection and death with increased park visitation as a result of voluntary adherence to behaviors that reduce COVID-19 risk.

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 & 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’, may have counted multiple visits by the same individuals and might not be representative of the larger population due to inability to obtain data from individuals who are not either using the apps or sharing their location information. All the big data studies identified in this review revealed considerable increases in nature contact (Lu et al., 2021b; Rice and Pan, 2021; Venter et al., 2020), whereas smaller datasets (e.g., survey data) utilized by studies in this review reported mixed findings regarding nature contact during the lockdown (Grima et al., 2020; Heo 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 its seasonal climate conditions rather than the COVID lockdown alone. 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. Robinson et al. (2021) identified the majority of the surveyed residents (72.3%) 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 (47.7%). 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. (2021; 2020) 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 (< 200m) increased during lockdowns.

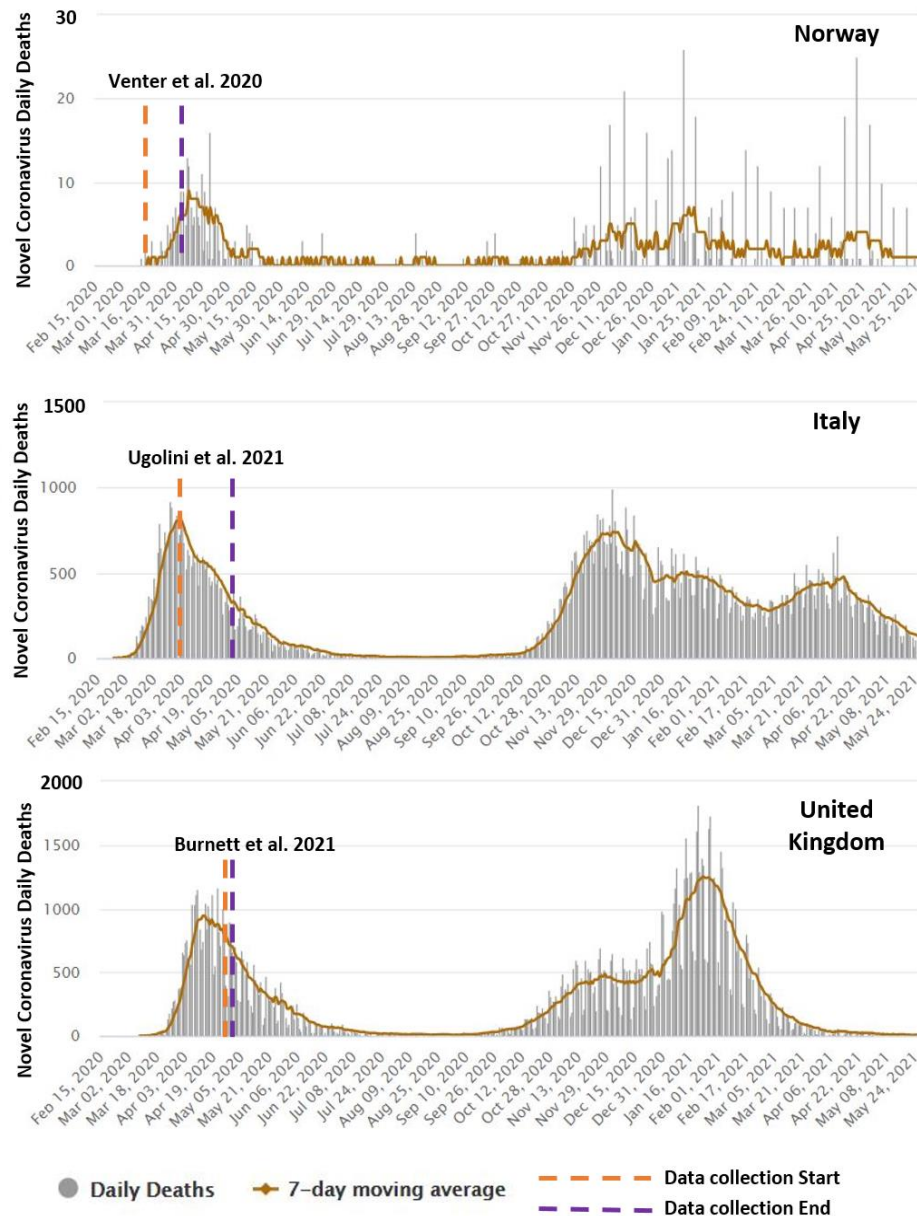


Figure 1: Coronavirus death rates in Norway, Italy, and United Kingdom, including identified studies that collected data on nature contact in these countries. In Norway, the daily death rates were below, and Venter et al. collected data before the first peak and observed a very high increase in nature visits. In Italy and the UK, daily death rates were between 500-1000 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/>.

Collectively, these findings indicate that people with access to private green spaces such as gardens had greater nature contact during the pandemic. Private gardens acted as a safe green space without the risk of being exposed to the coronavirus while maintaining social distancing guidelines (Poortinga et al. 2021; Shoari et al., 2020; Pan et al., 2021). This conclusion 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 (Mell and Whitten, 2021; Natural England, 2020). Implications of our findings on environmental and social justice are further discussed in **Section 3.4**.

Some of the studies on nature contact during lockdown also explored the underlying reasons for such modifications. Soga et al. (2021) 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 observed that several studies empirically 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 & 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., 2021). 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 et al., 2020). Opportunities for nature contact often depended on the capabilities (physical & 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 virtual reality [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 (Tester-Jones et al., 2020). Pfefferbaum and North (2020) pointed out that COVID-19 induced many stressors (e.g., infected family members, economic loss, pre existing physical or psychological conditions) that may have had the potential to impact mental health (e.g., depression, anxiety) during and after the lockdown. With changes in mental health, the demand for nature contact might also have been modified because people with reduced mental health and wellbeing were seeking refuge in nature.

During the lockdown, both the opportunity and capability of nature contact have been modified; however, the actual contact with nature may have been greatly influenced by personal motivations. The common positive, motivating factors for modified nature contact in terms of outdoor nature visits during lockdown included physically exercising, relaxing in nature, taking children outdoors, walking the dog, and meeting friends and family (Ugolini et al., 2020; Heo et al., 2021; Dushkova et al., 2021; Xie et al., 2020). In contrast, demotivating factors included over-crowding/distance concerns, lack of facilities (e.g., toilets in parks), not being able to meet with people outdoors, and difficulty accessing safe, publicly open green spaces in addition to the governmental rules to movement restrictions (O'Brien and

Forster, 2021; Shoari et al., 2020). The relative impact of these myriad factors on motivating and demotivating nature contact is currently 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 and lockdown (Volenec et al., 2021; Venture et al., 2021; Rousseau and Deschacht, 2020).

3.3 Associations between nature exposure and health

Several studies investigated associations between nature exposure and mental, physical, and general health, as well as wellbeing during the lockdown period. Because the lockdown limited the collection of objective health data (e.g., blood pressure, glucose level), studies usually adopted self-reported health and wellbeing measures and often focused more on mental health-related outcomes than physical health indicators. Additionally, a few studies investigated COVID-related health indicators such as infection rate and mortality to understand the neighborhood level correlation between nature exposure and these indicators. 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 (Dzhambov et al., 2020; Amerio et al. 2020; Soga et al., 2020; Pouso et al., 2021), stress (Ribeiro et al., 2021; Cindrich et al., 2021; Gola et al., 2021), anxiety (Sapano et al., 2021; Dzhambov et al., 2020; Pouso et al., 2021), loneliness (Soga et al., 2020), and increased positive emotions (Lades et al., 2020; Rodríguez-González et al., 2020) and general mental health and wellbeing (Robinson et al., 2021; Lehberger et al., 2021; Stieger et al., 2021) (Table 2). The direction, and consistency of relations varied by types of nature exposure; in particular, a view of nature (e.g., window view green) consistently showed stronger associations with lower depression, stress and anxiety level (Pouso et al., 2021; Soga et al., 2020; Sapano et al., 2021; Ribeiro et al., 2021) than neighborhood-level measures of nature accessibility or availability (Poortinga et al. 2021; Cheng et al., 2021). Similarly, more indoor plants showed consistent associations with lower depression and anxiety levels (Pérez-Urrestarazu et al., 2021; Sapano 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 (Lades et al., 2020; Lehberger et al., 2021; Cindrich et al., 2021; Browning et al., 2021).

The presence of a garden, spending time in the garden (for relaxation), and gardening during lockdown also were associated with several mental health outcomes. Theodorou et al. (2021) identified that gardening during the lockdown was directly associated with lower psychopathological distress and indirectly associated through lowering COVID-19 related distress. 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 (Lades et al., 2020, Sapano et al., 2021; Corley et al., 2021; Gola et al., 2021; Dzhambov et al., 2020). Additionally,

Lehberger et al. (2021) identified that garden owners had higher levels of mental wellbeing than non-garden owners.

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

In addition to actual nature exposure, virtual nature (e.g., digital videos, multisensory nature exposure, virtual reality) was associated with mental health conditions, although the amount of evidence was limited. Only a few studies explored associations between virtual nature and mental health during COVID-19 (Putrino et al., 2020; Zabini et al., 2020; van Houwelingen-Snippe et al., 2020). Zabini et al., (2020) showed that compared to videos of urban areas, watching videos of forested areas (approx. 5 min) for five days lowered perceived anxiety levels during lockdown. Similarly, Putrino et al., (2020) indicated that 15 min multisensory experiences of nature in a “Recharge Room” reduced stress levels among COVID frontline healthcare workers. Finally, van Houwelingen-Snippe et al., (2020) identified that watching digital nature while staying at home due to lockdowns increased nature connectedness and reduced loneliness. This collective evidence showed that when actual nature exposure (e.g., visiting parks, gardening) may not be available or limited during the strict lockdown period, virtual nature had the potential to lower the negative psychological impacts of COVID-19. While 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, other reviews and studies by White et al., (2018) and Yeo et al. (2020) reported that virtual nature could be an effective alternative when the opportunities of actual nature exposure are limited.

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; Sapano et al., 2021; Rodríguez-González et al., 2020). The studies as a whole suggested that nature exposure during lockdown likely had proactive effects in improving mental health conditions by reducing several antecedents of poor mental health conditions such as depression, anxiety, stress, and loneliness.

3.3.2 Wellbeing

A few studies explored if nature exposure was associated with happiness and life satisfaction during the lockdown. These studies reported that although people worried about the pandemic and its impacts, increased nature exposure was associated with greater happiness and life satisfaction (Soga et al., 2020; Leon et al., 2020; Stieger et al. 2020; Lehberger et al., 2021). These findings are in line with pre-COVID studies that reported living in greener areas was associated with increased happiness and life satisfaction among urban residents and linked with better mental health (White et al., 2013; Houlden et al., 2019; Chang et al., 2020). Considering the consistency of the evidence pre- and during COVID, we argue that nature exposure during lockdown helped people cope with the pandemic by reducing health-related risk factors, increasing happiness and life satisfaction, and overall reducing mental and physical health disease burden.

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 lockdown (Table 2). For example, Yang et al. (2021) noted that lockdown caused a reduction in the overall amount of leisure-time physical activity from approximately 5 to 4.5 hrs per 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, -22.23%). 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 (Ugolini et al., 2021; Astell-Burt and Feng 2021). Interestingly, Lesser and Nienhuis (2020) found people who usually were active (> 150 min of physical exercise per week) spent more minutes per 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 \leq 30 min in the last 7 days) were more likely to reduce their nature contact compared to people with the highest activity levels (\geq 150 min in the last 7 days). These studies suggest that there are 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 exposures had positive associations with physical activity level in the midst of the lockdown period.

In addition to physical activity health benefits, nature exposure was also positively associated with general physical health during COVID-19. Xie et al. (2020) and Corley et al. (2021) identified that visiting green spaces and increased garden use during lockdown was associated with improved self-rated physical health. 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

Nature exposure during lockdown has been associated with reduced sleep disturbance (Table 2). Inadequate sleep and sleep disturbances are considered common risk factors for several mental and physical illnesses such as obesity, cancer and cardiovascular diseases (Shin et al., 2020; Choi and Choi, 2020; Muscogiuri et al., 2019; Shankar et al., 2010). 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 the pre-COVID systematic review by Shin et al. (2020) on green space and sleep relations, where the authors reported green space exposure was associated with sleep quality and quantity. Based on this evidence, it can be argued that reducing sleep disturbances through nature exposure during the COVID lockdown might have had a critical impact on plummeting both mental and physical health problems.

3.3.3 COVID-19 incidence and mortality

The potential for associations between nature exposure and COVID-related mortality, infection rates, and prevalence rates have been investigated in several studies. The findings of these studies are somewhat conflicting, indicating both positive-negative relations between nature exposures and COVID-related variables. For example, at the early stage of the COVID-19 outbreak using 312 sample cities in China, Lui (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 2.6% less cumulative COVID-19 cases in 989 urban centers in the USA during their study period (March to May, 2020). Nguyen et al. (2020) studied 30,556 zip code level COVID-19 cases during June 2020 and observed that zip codes with higher levels of greenery along streets (>30%) had fewer COVID cases than zip codes with lower levels of greenery along streets. Klompmaker et al. (2021) found that higher neighborhood greenness was significantly associated with lower COVID incidence rates among 3,089 U.S. counties (6% reduction per 0.1 increase in NDVI), but greenness was not related to COVID mortality at population level but correlated for subgroup level mortality. 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; Lu et al., 2021a; Russette 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. county), metrics to measure nature exposure (e.g., NDVI vs. land use), consideration of other built and social environmental factors (e.g., population density, crowding, housing conditions) and lack of consideration on individual confounders (Helbich et al., 2021; Frumkin, 2021; You et al., 2020; Russette et al., 2021). Several studies extensively investigated the effect of built and social environmental factors on COVID-19 related outcomes (Hu et al., 2021; You et al., 2020; Huang et al., 2020; Nguyen et al., 2020; Lu et al. 2021a; You and Pan, 2020; Rojas-Rueda and Morales-Zamora, 2021). 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 a stronger association with COVID-19 transmission rate than residential nature availability and accessibility (You et al., 2020; Huang et al., 2020; Nguyen et al., 2020; Hu et al., 2021). In addition, other studies reported that social factors such as median household income, race/ethnicity, social deprivation and several other socioeconomic factors were strong predictors of COVID-19 mortality, morbidity and infection rate (Lu et al. 2021a; Russette et al., 2021; Egede and Walker, 2020). Studies have also linked air pollution (Wu et al., 2020; Frontera 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, these findings indicate that COVID-related health outcomes are 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 (Russette et al., 2021; You and Pan, 2020; Hu et al., 2021).

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; You et al., 2020; Lu et al., 2021b). 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 the violation of social/physical distancing regulations and increased the 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 Lu et al. (2021b) and You et al. (2020). These authors argued that at 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.

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

We identified six studies that examined how associations between nature exposure and health during lockdown varied by socioeconomic status (SES). Only one of these (Burnett et al., 2021) showed that lower-SES groups benefited more from nature exposure than higher-SES groups in regard to mental health; the remaining five 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 & Feng, 2021). Similarly, no differences in nature exposure duration or frequency were identified by levels of neighborhood deprivation among survey responses collected between April and July, 2020, mostly from the UK (Robinson et al., 2021). Further, 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). Also, 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 between March and May, 2020 (Riberio et al., 2021). In contrast, a second UK survey in April/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. In the single study on the topic that examined effect modification by area-level income (Klopmaker et al., 2021), the protective association of green space on COVID incidence was stronger among U.S. counties with higher median household incomes than other counties, yet no differences by income were found for COVID mortality.

Several of these same studies also tested for differences in nature exposure and associations with health by gender/sex, finding no differences in most analyses. The Australian survey mentioned above found that men spent less time in natural areas during lockdown but they also reported that these areas provided more solace, respite, and feelings of social connection than women (Astell-Burt & Feng, 2021). The April 2020 U.K. survey found the opposite, however; women reported that green space benefited their health more during the lockdown than before the lockdown relative to men (Burnett et al., 2021). In that U.K. study, 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. No differences were also found in associations between nature deprivation during lockdown and psychological wellbeing between men and women in the U.S. (Tomasso et al., 2021). Similarly, no differences between men and women were observed for the association between somatization or psychological distress during lockdown and nature exposure in Spain or Portugal (Riberio et al., 2021). Essentially no sex/gender differences were found in associations between public green space proximity and well-being or general health in a UK study administered in March/April and then again in June/July, 2020 (Poortinga et al., 2021). However, the UK study authors also observed that having a private garden was associated with higher levels of well-being in men than in women.

A few studies have examined the potential for differential use or effects of green space among certain racial/ethnic groups. In the U.S., white respondents reported lower levels of psychological well-being when they felt that the COVID-19 pandemic had restricted their access to nature; in contrast, non-white respondents reported higher levels of psychological well-being when they felt restrictions in nature access during the pandemic (Tomasso et al., 2021). U.S. counties with greater shares of Black residents showed no differences in associations between green space and COVID 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 (Klopmaker et al., 2021). This finding suggests harmful associations between green space and COVID mortality in areas with low levels of Black residents. A second study restricted to the most urbanized

U.S. counties found related findings; green land coverage reduced racial/ethnic disparities in COVID infection rates between the Black and white people (Lu et al., 2021a). Lastly, there were no differences in green space visits, visitation changes before/after the pandemic, or perceived mental health benefits of visits during lockdown between people identifying as white, Black, Asian, or as another racial/ethnic minority in the UK (Burnett et al., 2021).

4. Discussion

4.1 Summary and interpretation of main findings

In this literature review, we synthesized research carried 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 **Figure 2**. Except for access to public natural spaces such as urban parks, during COVID-19 lockdown, opportunities for nature exposure have generally increased. Some exposure types witnessed greater changes than others, such as reporting of increased green view through windows, additionally gardening highly 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 (more in section 3.2.2).

The changes in nature exposure during lockdown were associated with several health-related outcomes. These associations were generally in the positive direction, indicating that increased nature exposure during lockdown generally improved health and wellbeing and that nature exposure showed protective effects in coping with mental and physical health conditions. As presented in Figure 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). Viewing nature through windows, spending time in nature, gardening all indicated positive influence on mental health related outcomes (more in section 3.3.1). Notably, the studies 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 also reported to improve mental health conditions (Soga et al., 2017; de Bell et al., 2020; Chalmin-Pui et al., 2021). Considering the strong evidence of the positive effects of gardens in pre-COVID and lockdown period studies, it can be argued that private green space such as gardens provided considerable mental health benefits during COVID-19 lockdowns.

Based on the consistent evidence, we argue that nature plays a vital role in lowering mental health burden during COVID-19 lockdowns. The potential positive effects of nature exposure in improving mental health conditions is also supported by widely recognized stress reduction (Ulrich et al., 1991; Ulrich, 1984) and attention restoration theories (Kaplan and Kaplan, 1989; Kaplan, 1995).

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

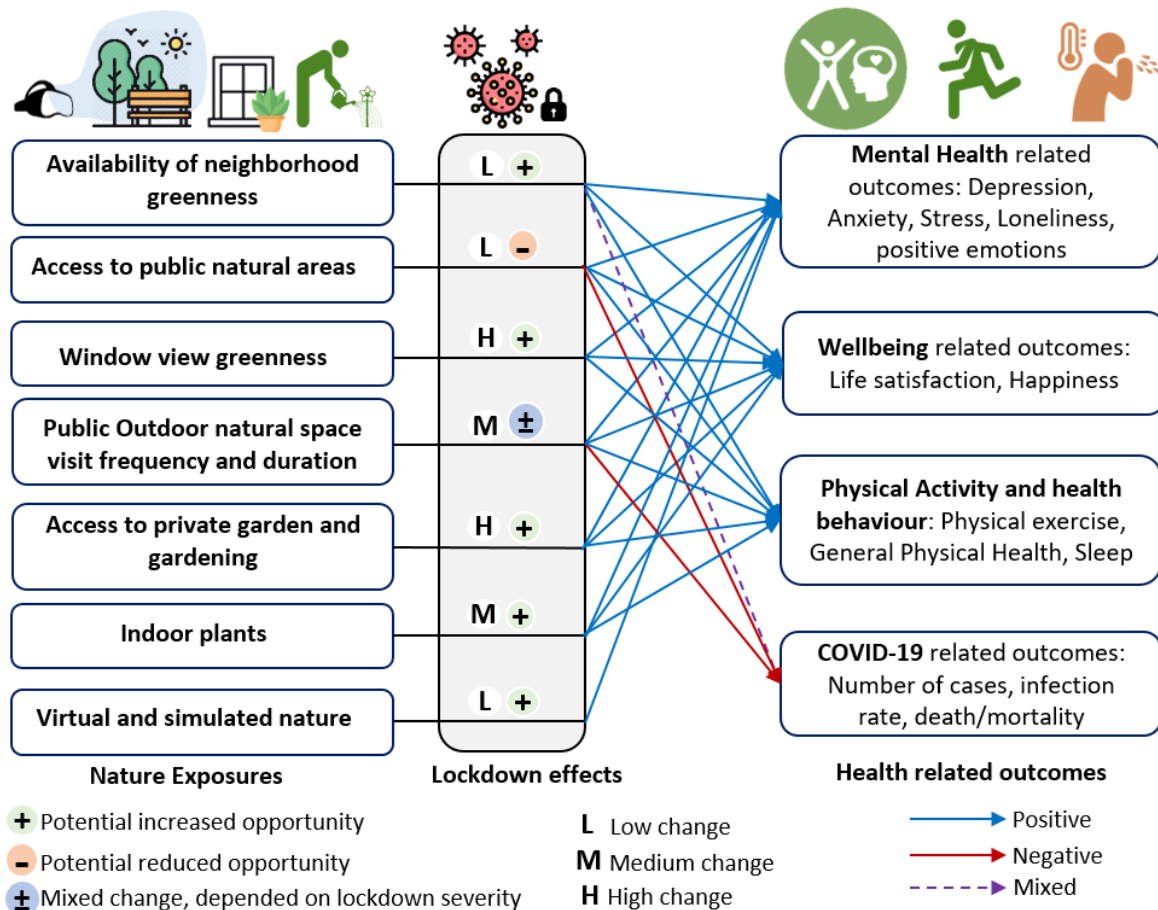


Figure 2: Nature exposure types, COVID-19 lockdown effect on exposure, and nature exposure associations with health-related outcomes. The blue arrows indicate dominant positive, the red arrows indicate dominant-negative, and the dotted arrow indicates mixed associations of nature exposure with health-related outcomes.

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 Figure 2). In the first domain, studies indicated that nature exposure might have been associated with lowering physical inactivity during COVID-19 and thus might have had physical health benefits specifically for COVID-19 patients. Sallis et al. (2021) and Després (2021) noted that physically-inactive COVID-19 patients were more vulnerable to critical health conditions during and after the acute infection period. 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 and other activities that promote instoration; Markevych 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 (Sallis et al., 2021; Kluge et al., 2020; Lee et al., 2012). 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 (Figure 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 lockdown. Simultaneously, nature exposure might have impacted COVID-19 incidence and mortality rates as a result of violations in social distancing regulations and increased coronavirus transmission. These phenomena likely depend on several factors such as the size of public parks, number of people visiting, types of activities (e.g., meeting others), and opportunities to maintain social distancing (Shoari et al., 2020; Pan et al., 2021). Nonetheless, the net 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; Rowe et al., 2021; Dominski and Brandt, 2020). Further research is warranted to fully understand the net effects of nature exposure on physical health outcomes over the lockdown period.

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 (Rigolon et al., 2021; Bolte et al., 2019; Kabisch, 2019). Despite reasons to believe that green space might have stronger associations for disadvantaged groups, the currently available evidence does not show that nature exposure helped to overcome any health disparities during lockdowns. The SES and race/ethnicity findings might be explained by such vulnerable populations

more often working in employment sectors that did not allow them to socially distance/isolate (Selden & Berdahl, 2020; Jay et al., 2020). Such restrictions may have reduced opportunity to access nature near their residential environment during breaks from telework (Honey-Roses et al., 2020), thus outweighing the additional benefits such populations may otherwise see from green space exposure relative to less vulnerable populations (Rigolon et al., 2021). Meanwhile, the lack of differences by sex/gender can be expected since the larger body of literature on nature and health shows no consistent direction in whether women or men benefit more from myriad health outcomes, as has been reviewed here (Bolte et al., 2019). 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 COVID-19 pandemic has had devastating impacts on health systems globally, in particular cities were the epicenters of the infection (about 90% of the COVID-cases in urban areas; UN, 2021a). Many urban residents, in particular, faced the unintended negative consequences of lockdowns in terms of mental and physical illness. The available evidence overwhelmingly supports the conclusion that nature exposure was associated with better mental and behavioral health during COVID-19 lockdowns. However, because the majority of the studies were cross-sectional in design, causal relations cannot be confirmed. Nonetheless, 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 were 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's Sustainable Development Goals (UN, 2021b) 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 (**Figure 3**).

4.2.1 Nature based solutions (NBS)

NBS is an umbrella concept covering 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. Details of such societal challenges and ecosystem approaches within NBS have been discussed at length in Cohen-Shacham et al., (2016; 2019) and IUCN (2020). Among the ecosystem based approaches with NBS, green infrastructure (GI), and forest landscape restoration focusing on urban forestry (UF) are two crucial approaches to maintain and improve health and wellbeing in cities during crises like COVID-19 lockdowns. 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., 2021; Nieuwenhuijsen, 2021; Escobedo et al., 2019; Kabisch et al., 2017; Tzoulas et al., 2007).

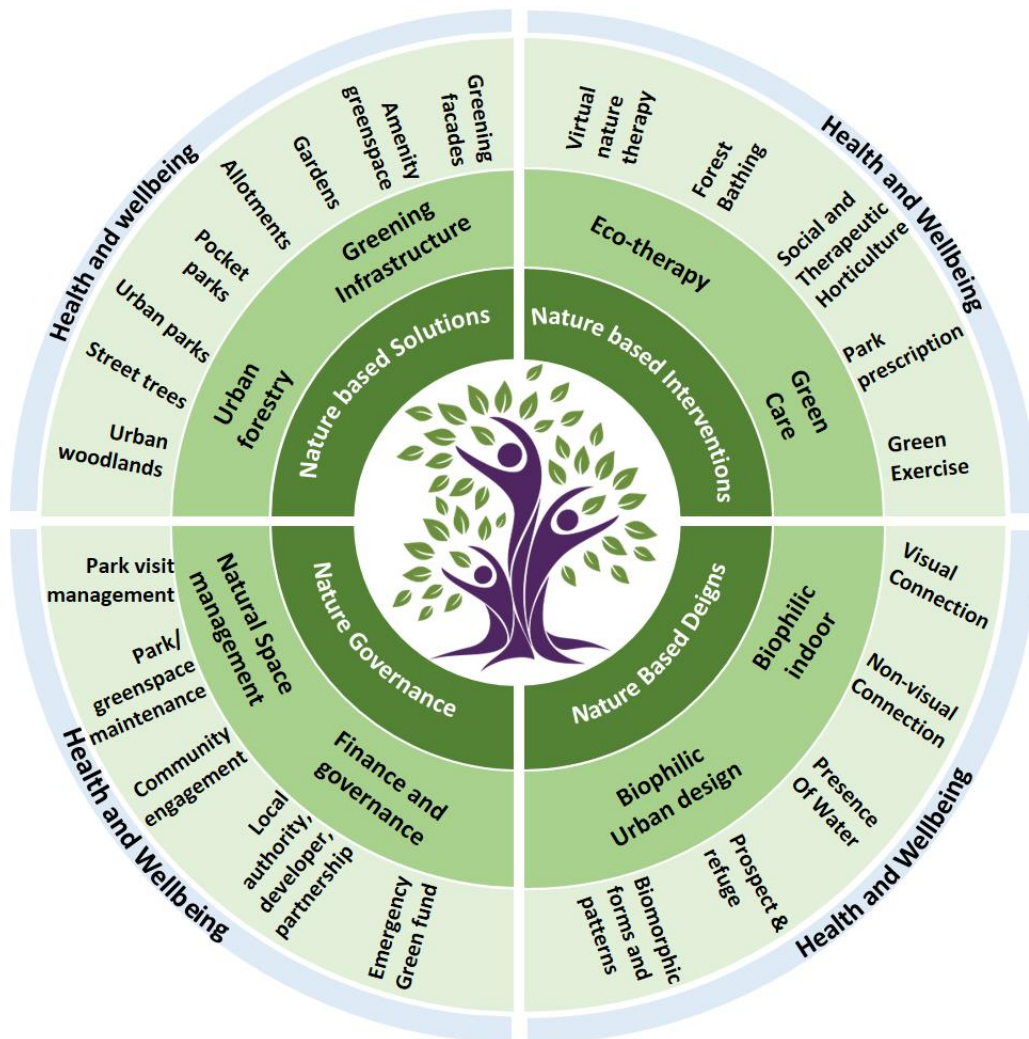


Figure 3: Nature based policies and practice dimensions to increase nature exposure through nature based solutions, interventions, design and governance. Each thematic area provides examples of broad and specific policies and practice elements at multiple levels to ensure nature exposure contributes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

Several elements of GI and UF could contribute to short term COVID-19 recovery and long term resilience for health and wellbeing in response to future emergencies (Figure 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 UF 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 be useful in delivering multiple health benefits within a shorter timeline (Sivak et al., 2021; Hanzl, 2020). For longer-term resilience, other GI and UF elements (e.g., urban parks, woodlands) can be implemented through spatial and urban planning strategies at multiple spatial scales (e.g., neighborhood, city) (Mell, 2021; Dushkova and Haase, 2020). 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 (van den 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 meters from the nearest green space that allows for multiple recreational activities (<https://nbsi.eu/>).”* This rule may assist in developing long-term GI and UF planning to achieve improved health and wellbeing of each individual even during crisis situations like COVID-19. As a whole, we recommend that NBS should be integrated into the further planning and policies to rebuild cities and communities to ensure greater opportunities of nature exposure to improve or maintain health and wellbeing during emergencies.

4.2.2 Nature based interventions (NBI)

Although NBS 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 (Holland et al., 2021; Bartman et al., 2019). To be more certain about obtaining health benefits from nature exposure, a wealth of existing literature suggests adopting and implementing nature-based interventions (Wilkie and Davinson, 2021; Garside et al., 2021; Masterton et al., 2020). Nature-based interventions differ from nature-based solutions in the former’s focus on people and their behavior regarding intentional nature contact through interventions broadly grouped under green care and eco-therapy (Shanahan et al., 2019; Herper et al., 2021). Figure 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 (Wilkie and Davinson, 2021; Chaudhury and Banerjee, 2020; Kotera et al., 2020; Shanahan et al., 2019). 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 have great potential to mitigate PTSD, depression, stress, and other mental health-related issues associated with COVID-19.

Based on these observations, we recommend development and implementation of NBI to recover from the COVID-19 negative consequences on mental health. However, care should be taken in designing NBI during lockdowns so that the interventions do not increase the risk of COVID-19 infection 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., 2018; Yeo et al., 2020; Annerstedt et al., 2013).

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 (Ryan et al., 2014; Kellert, 2018; Kellert et al., 2011). 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; Figure 3) which may reflect the nature-health relationships in varying built environment contexts. In particular, visual connection with nature should be considered as a critical design principle for buildings. As we discussed, window view green has shown consistent associations with multiple health outcomes, and building design should consider placing windows in ways that maximize the visual connection with outdoor greenery.

Non-visual connections (e.g., auditory) should also be carefully considered in designing buildings and outdoor spaces. Such as, priority should be given in maximizing nature sounds over urban sounds (Browning et al., 2014). In this regard, Qiu et al., (2021) identified that during COVID-19, people with higher mental stress obtained a greater mental restoration through water sounds compared to pre-COVID samples. Based on such evidence, the presence of water such as small-scale running water both indoor and within the neighborhood should be considered as a key design principle to increase water exposure during staying at home. Design patterns such as prospect and refuge, biomorphic forms should also be integrated in urban design to increase overall nature connections through multisensory experience of nature as part of everyday life (Browning et al., 2014; Ryan et al., 2014). It should be noted that, ‘Biophilic cities’ (Biophilic Cities, 2021), a global 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 NBS, 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 (Figure 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 distancing (Shoari et al., 2020; Moore and Hopkins, 2021). 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 NBS, NBI, and NBD are often challenging due to monetary constraints, lack of awareness, and inadequate leadership (Mell, 2021; Kabisch, 2015; Garside et al., 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 (Figure 3). We recommend creating partnerships between local authorities, developers, designers, and community groups when implementing NBS and NBD in new developments (e.g., housing) and retrofits of existing neighborhoods. Care should be taken in implementing NBS in areas such as historically disinvested neighborhoods, because developing new green spaces in such areas may result in green gentrification (Rigolon and Németh, 2020; Wolch et al., 2014) and the displacement of low-income residents for whom the NBS strategies were designed to benefit (Wolch et al., 2014; Cole et al., 2017). Funds to support NBS, 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 (Furmkin, 2021; Mell, 2021; Mell and Whitten, 2021).

4.3 Conclusion

In this narrative review, 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 lockdowns. During the first year of COVID-19 pandemic, characterized by widespread lockdowns, various types of 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 of the evidence suggests several critical roles of nature exposure during the first year of the COVID-19 pandemic:

- During COVID-19 lockdowns, many people had increased contact with nature. In particular, spending time in private green spaces such as gardens considerably increased, along with increased visits to select outdoor natural areas. However, the duration and frequency of visits to public natural areas were influenced by the severity of lockdown, COVID-19 mortality rates, and socio-cultural factors.

- Nature exposure during the COVID-19 pandemic was consistently associated with improved mental health and wellbeing. Studies indicated increased nature exposure of various types were related to lower 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. A few studies suggested that nature visits might be associated with greater rates of COVID-19 transmission and mortality when proper social distancing measures were not maintained.
- Evidence was mixed regarding the modifying effects of age, gender, socioeconomic status, and race/ethnicity on nature-health relationships.

In summary, nature exposure played an important role during the first year of the COVID-19 pandemic, characterized by widespread lockdowns, and it may have prevented further mental and physical health deterioration at a larger 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 solutions, interventions, biophilic designs, and governance strategies and practices.

Appendix:

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 (2020/3/1:2021/4/30[pdat])) ; **Results = 373***

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") AND (LIMIT-TO (LANGUAGE,"English")) ; **Results = 414***

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= (2020-03-01/2021-04-30)) AND LA= (English); **Results = 433 (with exact search option)***

Declaration of competing interest

We declare that we have no conflicts of interest.

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