

## Mental health, greenness and nature related behaviours in the adult population of Stockholm County during Covid-19-related restrictions

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### Abstract

International data suggests that exposure for nature is beneficial for mental health and well-being. The restrictions related to Covid-19 pandemic have created a setting that allows us to investigate the importance of greenness exposure on mental health during a period of increased isolation and worry. Based on 2060 responses from an online survey in the Stockholm County, Sweden, we investigated: 1) whether the Covid-19 pandemic changed peoples' life-style and nature-related habits, and 2) if peoples' mental health differed depending on their exposure to greenness. Neighbourhood greenness levels were quantified by using the average Normalized Difference Vegetation Index (NDVI) within 50m, 100m, 300m, and 500m buffers surrounding the participant's place of residence. We found that the number of individuals that reported that they visited natural areas "often" was significantly higher during the pandemic than before the pandemic. Higher levels of greenness surrounding one's location of residence were in general associated with higher mental health/wellbeing and vitality scores, and less symptoms of depression, anxiety, and perceived and cognitive stress, after adjustments for demographic variables and walkability. In conclusion, the results from the present study provided support to the suggestion that contact with nature may be important for mental health in extreme circumstances.

Key words: COVID-19, greenness, mental health, societal change, social isolation, psychological factors, resilience

## Introduction

Countries worldwide have taken action to control the population movement in response to the Covid-19 pandemic. The aim of the restrictions has been to reduce disease transmission by minimizing physical contact between people. These measures, however, have affected a much wider range of societal aspects than the disease spread, with consequences on economy, social relations, health related behaviours, as well as being disruptive for services and education (1-3). People that are already struggling because of low income, social isolation or poor health are also likely to be the most vulnerable to the adverse effects of the pandemic-related societal actions. Among those are the elderly people, who have the highest risk of severe Covid-19 infection and at the same time are at greatest risk of social isolation, as they are less likely to use online communication (1). People with underlying mental health conditions may be at risk of ending up increasingly isolated and, consequently, experience impaired mental health, which may result in development of severe depression/anxiety-related symptoms (1, 4, 5). Isolation may also increase the problems with substance abuse and potentially affect the number of cases of family violence (1). In addition, for individuals on low income or on precarious contracts, the effects of the pandemic may become particularly severe as they already have poorer health and have an increased likelihood to be in insecure work without financial reserves (1). All this has raised concerns about the mental health consequences that this period of time may have on public health (2, 6, 7).

The Covid-19 pandemic-related restrictions in the Swedish society have been relatively mild compared to most European countries (3). Still, during the spring 2020, the population of Sweden were recommended to, as much as possible, work from home, limit their social contacts and avoid the use of public transport. In addition, no social mass gatherings were allowed to take place and the majority of the flights and some lines of public transport were temporarily stopped. The activity of high schools and universities was mostly taking place through digital platforms. For the elderly, it was strongly advised to self-isolate at home, and in the care-homes, the contact with non-staff was very limited. Since, loneliness and isolation have been a problem in the Swedish society also before the Covid-19 pandemic, concerns have been raised about the potential mental health effects of the pandemic restrictions. According to Statistics Sweden, approximately four percent of the adult Swedish population were estimated to be socially isolated in 2016-2017, and the loneliest ones were the elderly (8). Loneliness is a concern for both physical and mental health providers, as research is increasingly linking social isolation to declining physical, mental, and emotional well-being (9).

During the time of increased uncertainty, nature around our homes may play a key role in mitigating against adverse mental health outcomes (2, 10). A myriad of scientific studies have suggested that experiencing greenness and nature is associated with mental health benefits (11). Greenness exposure has been linked to increased positive affect (12-14), happiness (15), increased engagement in social interactions (7, 16, 17), enhanced sense of meaningfulness (18), decreased mental distress and improved manageability of life tasks (16, 19-21). In addition, nature experience has been shown to be positively associated with various aspects of human cognitive function, memory and attention, impulse control, as well as children's school performance, and creativity (22-30).

When range and contexts of people's movements are curtailed, greenness exposure close-by homes, either through windows or in the immediate neighbourhood, including balconies and domestic gardens, may become increasingly important for psychological restoration and in support of mental wellbeing (2, 10, 31). Several studies have indicated that seeing greenness through window may promote health and wellbeing by providing micro-restorative episodes that promote healing (32-35), facilitate psychological restoration (36), increase recovery from stressful events (37) and improve affective and functional wellbeing (38). Furthermore, being able to enjoy green window views has been seen to positively affect an individual's cognitive capacity (39) increase life- (40) and

job-satisfaction (41) and promote fascination and a sense of being away from everyday life (42). In a recent study, Dzhambov et al 2020 (10) reported that the university students in Bulgaria, who were forced to self-isolate at home because of the Covid-19 restrictions, but had abundant greenery visible from their home windows or in the neighbourhood, showed both reduced symptoms and rates of depression and anxiety. Spending time in a domestic garden has, among other health effects, been associated with reduced depression and anxiety (43-45). However, it is important to remember that having a domestic garden is also strongly associated with socioeconomic status (46). Still, the perceived restrictiveness of private gardens has been reported to rank higher than of other private spaces (47) and gardening has been associated with reduced anxiety, depression, and many other mental health benefits (43, 48).

Several studies have already reported increased number of visits to urban natural areas, such as parks and urban forests during the Covid-19 restrictions (49, 50). A recent Japanese study also found that increased exposure to neighbourhood greenness and the frequency of green area use during the pandemic was positively associated with levels of self-esteem, life satisfaction and subjective happiness, as well as negatively associated with depression, anxiety and loneliness (2). In the present study, we investigate the possible changes in people's habits of visiting nature during the spring 2020, and also whether the mental health estimates during the same period of time were associated with the exposure to neighbourhood greenness and to the nature-related behaviours in the adult population of Stockholm County, Sweden. The study was based on 2060 self-reported responses to a questionnaire sent out in June 2020.

## Materials and Methods

### Study design and sampling

Between June 05 and August 01, 2020, we conducted an online survey among adult residents ( $\geq 20$  years) in three urban municipalities, eight suburban municipalities and one rural municipality (see Supplementary material C) in Stockholm County. The Swedish Population Register (51) provided the postal address data of the potential study participants (5000 men and 5000 women, randomly selected within the municipalities). We approached the potential participants by written requests to participate in a survey on greenness and mental health. The potential study group received a link to a web-questionnaire in Questback (<https://www.questback.com>). This survey was administered in Swedish and included questions about sociodemographic factors, daily activities and habits, mental health, and the neighbourhood walkability (see the English translation of the questions and response alternatives that the present study is based on in the Supplementary Material A). The participants were only able to submit their responses once. Two thousand sixty (2060; about 20 %) individuals submitted their survey responses. In general, the study design and procedure followed the general principles outlined in the Declaration of Helsinki. By filling in the survey, the study participants agreed that their personal information was processed and stored according to the General Data Protection Regulation in the European Union. The study was approved by the Swedish Ethical Review Authority.

### Exposure assessment

We transformed the participant addresses to geographic coordinates by using the Open Streetmap ([www.openstreetmap.org](http://www.openstreetmap.org)) and the GIS (Geographic information system) software Qgis ([www.qgis.org](http://www.qgis.org)). In about 10 % of cases, when the Open Streetmap was unable to find the address coordinates, the addresses were geocoded manually by using Google Maps in the Chrome software.

Greenness exposure

Normalized Difference Vegetation Index (NDVI) (26), derived from Landsat 8 composite images (at a resolution of 30x30m) was used to estimate residential greenness. NDVI is a remotely sensed measurement obtained by visible red (RED) and near infrared (NIR) radiation interacting with photosynthetic tissue in plants, and is calculated using formula:  $NDVI = (NIR - RED) / (NIR + RED)$ . NDVI values range from -1 to +1, where higher values indicate more green vegetation foliage. To avoid possible effects of local level cloud contamination (resulting in false low values) and the year-specific variation (due to, for example, inter-year differences in precipitation) we used the highest NDVI value of the three consecutive years (2017, 2018 and 2019), within 50m, 100m, 300m, and 500m buffers surrounding the participants place of residence. To avoid underestimation of the NDVI exposure values, we excluded surfaces covered with water (represented by negative NDVI values) from the buffer areas.

Other variables

Walkability

We used the Health by Design questionnaire “How Walkable is Your Neighbourhood?” ([www.healthbydesignonline.org](http://www.healthbydesignonline.org)) to acquire the neighbourhood walkability scores (Supplementary Material A). Since the walkability values in Swedish cities are generally very high, the thresholds recommended by the authors of the survey for categorisation of the responses were not suitable. Instead the walkability scores were analysed either as a continuous variable (i.e. Table 6 &7) or categorized according to the interquartile level (i.e. Table 1).

Table 1. Background characteristics related to NDVI values in 50m buffers below resp. above the median levels (NDVI=0.46).

Variable name	NDVI low	NDVI high	P-value
	N (%)	N (%)	
<i>Sex</i>			<b>0.232</b>
<i>Females</i>	583 (51)	556 (49)	
<i>Males</i>	447 (49)	474 (51)	
<i>Age group</i>			<b>0.865</b>
<i>&lt; 70 years</i>	842 (50)	839 (50)	
<i>≥ 70 years</i>	188 (49)	192 (51)	
<i>Educational level</i>			<b>0.000</b>
<i>Primary education</i>	42 (37)	71 (63)	
<i>Secondary education</i>	247 (45)	307 (55)	
<i>Higher education</i>	734 (53)	644 (47)	
<i>Income</i>			<b>0.000</b>
<i>&lt; 225 tSEK</i>	111 (40)	169 (60)	
<i>225- 450 tSEK</i>	304 (45)	377 (55)	
<i>&gt; 450 tSEK</i>	600 (56)	467 (44)	
<i>Country of Birth</i>			<b>0.019</b>
<i>SSB*</i>	897 (49)	930 (51)	
<i>All other countries</i>	127 (57)	94 (43)	
<i>Alcohol consumption</i>			<b>0.019</b>
<i>Below risk</i>	831 (48)	885 (52)	

<i>Above risk</i>	183 (57)	136 (43)	<b>0.000</b>
<i>Walkability</i>			
<i>Low</i>	243 (38)	397 (62)	
<i>Average</i>	323 (48)	349 (52)	<b>0.017</b>
<i>High</i>	454 (63)	270 (37)	
<i>Sitting score</i>			
<i>Low</i>	324 (47)	371 (53)	<b>0.020</b>
<i>Average</i>	338 (49)	356 (51)	
<i>High</i>	333 (54)	280 (46)	
<i>Frequency of nature visits</i>			<b>0.020</b>
<i>Often</i>	792 (49)	835 (51)	
<i>Seldom</i>	238 (55)	195 (45)	

\*SSB – Sweden, rest of the Scandinavia and the Baltic States

### *Sociodemographic variables*

Based on available literature, we identified factors previously considered as potential confounders or effect modifiers in studies investigating associations between mental health outcomes and residential greenness. The data from Swedish Population Register contained, in addition to the personal addresses, information about the age and sex of the potential participants. Information about individuals' education level, annual income and ethnicity were collected in the survey (Supplementary Material A).

### *Frequency of nature visits*

We estimated the individual level frequency of nature visits by using the participants' responses to the questions: "On average, how often did you visit nature areas, such as parks/forests/bodies of water, during the summer months before the Covid-19 pandemic?"; "On average, how often did you visit nature areas, such as parks/forests/bodies of water, during the winter months before the Covid-19 pandemic?"; and "During the Covid-19 pandemic, on average, how often did you visit nature areas, such as parks/forests/bodies of water?" (see the Supplementary Material A, 2.1.). The response alternatives to the above questions included: "Every day", "One to several times per week", "One to several times per month", "One to several times per year", and "Never".

In Table 1 and 2, we present the proportion of study participants that visited natural areas "often". This proportion was obtained by pooling (separately for each of the questions above) the proportion of individuals that responded with "Every day" and "One to several times per week" (all the other responses were pooled to the proportion of individuals that visited nature areas "seldom"). Since the proportion of people that visited natural areas "often" before the Covid-19 pandemic differed between summer (81 %; generally acknowledged as April-September) and winter (54 %; October-March), while the period of the Covid-19 pandemic included both "winter" and "summer" months, transformation of the data was necessary to make the before and during pandemic estimates comparable. We estimated that in June, when the majority of the study participants (about 95%) responded to the survey, the period of epidemic had consisted of approximately 1.5 winter (middle-February-March) and 2 summer months (April-June). Accordingly, we combined the respective responses to the questions about the frequency of nature visits during winter and summer before the Covid-19 pandemic into a time-weighted estimate ( $= (1,5/3,5 * \text{frequency of nature visits during summer}) + (2/3,5 * \text{frequency of nature visits during winter})$ ), and used this estimate as a proxy for

how often the respondents would have been expected to visit the nature during a corresponding time period if the pandemic had not occurred.

Table 2. The percentage of people that reported that they visit natural areas “often”. (\*p<0.05; CI – Confidence Interval)

Population	n	before Covid-19 % (95 % CI)	during Covid-19 % (95 % CI)	difference % (95 % CI)
Total	2059	65.98 (64.27;67.69)	79.02 (77.26;80.78)	+13.04 (14.77;11.31)*
Age	< 70 years	63.43 (61.52;65.34)	77.56 (75.56;79.56)	+14.13 (16.08;12.18)*
	≥ 70 years	77.31 (73.71;80.9)	85.49 (81.93;89.05)	+8.18 (11.83;4.53)*
Sex	men	62.25 (59.58;64.92)	73.91 (71.07;76.76)	+11.66 (14.21;9.11)*
	women	83.14 (80.97;85.32)	83.14 (80.97;85.32)	+14.15 (16.5;11.79)*
Education	primary	67.89 (60.06;75.71)	71.68 (63.25;80.12)	+3.79 (10.66;-3.08)
	secondary	64.7 (61.32;68.07)	75.63 (72.05;79.22)	+10.93 (14.3;7.56)*
	higher	66.54 (64.48;68.59)	81.06 (78.99;83.13)	+14.52 (16.64;12.41)*
Ethnic origin	born in SSB <sup>1</sup>	67.32 (65.51;69.14)	80.95 (79.14;82.77)	+13.63 (15.42;11.84)*
	not born in SSB <sup>1</sup>	55.87 (50.82;60.91)	64.23 (58.2;70.26)	+8.36 (14.39;2.34)*
	both or one of the parents from SSB <sup>1</sup>	67.32 (65.51;69.14)	80.95 (79.14;82.77)	+13.63 (15.42;11.84)*
	neither mother nor father from SSB <sup>1</sup>	55.87 (50.82;60.91)	64.23 (58.2;70.26)	+8.36 (14.39;2.34)*
Residential area walkability	Poor (lowest tertil)	64.87 (61.8;67.93)	80.31 (77.22;83.4)	+15.45 (18.64;12.26)*
	Good (2nd tertil)	65.99 (63;68.97)	78.87 (75.77;81.96)	+12.88 (15.91;9.85)*
	Very Good (highest tertial)	66.63 (63.72;69.54)	77.9 (74.87;80.93)	+11.27 (14.12;8.41)*
Residential NDVI within a 50m buffer	Low NDVI (0,236-0,343)	64.82 (61.83;67.8)	76.42 (73.24;79.6)	+11.6 (14.74;8.46)*
	Average NDVI (0,344-0,431)	65.54 (62.51;68.56)	79.3 (76.26;82.34)	+13.77 (16.75;10.78)*
	High NDVI (0,5- 0,559)	67.6 (64.71;70.48)	81.34 (78.42;84.26)	+13.74 (16.61;10.88)*

<sup>1</sup>SSB – Sweden, rest of the Scandinavia and the Baltic States

In cases when a participant had responded with “One to several times per year” or “Never” to a question about the frequency of nature visit before respectively during the pandemic, this inquiry was followed by a question about the reasons for not visiting the nature areas more often (“What was your reason for, before/during the Covid-19 pandemic, not to visit nature areas more often?”). If the query about nature visit frequency was answered with “Every day”, “One to several times per week” or “One to several times per month” the query was followed by the inquiry of: “What was your reason to visit nature areas before/during the Covid-19 pandemic?”, and thereafter “What kind of natural areas did you visit during the Covid-19 pandemic and how often?” (see the Supplementary Material A, 2.2.-2.4. for the response alternatives).

#### *Alcohol consumption*

Data about alcohol consumption before and during the Covid-19 pandemic was estimated by combining the responses to: “How often did you drink alcohol before the Covid-19 pandemic/during the Covid-19 pandemic?” and to: “How many glasses/day did you typically drink when you drank alcohol before the Covid-19 pandemic/during the Covid-19 pandemic?” (One standard glass corresponds to 12 g of alcohol (52); Supplementary Material A). Definitions of threshold levels for harmful alcohol consumption vary largely between the recommendations from different studies and authorities (52-56). We set the amount of  $\leq 7$  standard glasses of alcohol/week for women and  $\leq 10$  standard glasses of alcohol/week for men as the threshold for “low risk for alcohol-related health problems” (used in, for example, 57). Individuals with estimated consumption higher than this value were thus categorized as having “an increased risk for alcohol-related health problems”.

#### *Physical inactivity*

The “sitting score” derived from the answers to the classic International Physical Activity Questionnaire - Short Form (IPAQ-SF). The sitting score was estimated from the responses to the questions: “Before the Covid-19 pandemic / During the Covid-19 pandemic, how much time did you usually spend sitting on one of days on a regular week?” (see Supplementary Material A: 4). The reason to use the sitting score rather than the total physical activity scores was that a comparably larger proportion of data was missing among the physical activity data than among the sitting scores, thus making it impossible to estimate the total physical activity scores for as many people as we had the physical inactivity data.

#### *Outcome variables*

##### *RAND-36: mental health/wellbeing and vitality scores*

The RAND-36 was originally developed to measure health related quality of life (58). In the present study, we used the subscales of mental health and wellbeing (four items), and vitality (four items) (for more information about scoring and questions see Supplementary Material A: 5.2.). We computed the mean scores (according to 58) for each of the subscales and used these in the further analyses. Both subscales measured symptoms during the last month with higher values corresponding to beneficial mental health effects.

##### *SCL90: core depression and anxiety symptoms*

We used the core depression subscale from the Hopkins Symptom Checklist 90 to estimate the occurrence of depressive symptoms (sum of the scores for six items; see Supplementary Material A: 5.4). Due to space limitations in the questionnaire, the anxiety scores were only based on two items from the SCL anxiety subscale (SCL-90-CD; see Supplementary Material A) (59, 60). The excluded items of the original anxiety subscale focused on symptoms related to repetitive behaviours (such as

repetitive washing, control behaviours), avoiding public places, and being uncomfortable eating and drinking out, e.g. in bars or restaurants. We judged these inquires less relevant for capturing anxiety symptoms during the Covid-19 pandemic, since such behaviours were part of the behavioural recommendations from the public health authorities in order to restrict the Covid-19 transmission. Both outcome measures (depression and anxiety) measured symptoms during the last week. Lower subscale values correspond to beneficial mental health effects, i.e. a lack of the respective symptoms.

Perceived Stress Scale- PSS

We estimated the perceived stress by using the sum of the scores of a six-item version of the Perceived Stress Scale (61). The included questions focused on symptoms experienced during the last month and based on the classic PSS four-item short scale with two additional items, which have shown consistently high factor loadings in prior studies (62) (see Supplementary Material A: 5.1. for more information about scoring and included questions). Lower values correspond to beneficial mental health effects.

The Cognitive Stress Score

We used the average values of the cognitive stress scale, originating from the Stress Profile (63), to estimate cognitive stress symptoms, experienced during the last month, in our study participants (see Supplementary Material A: 5.3.). The four questions target problems with concentration, memory, thinking clearly and making decisions, and have been found to be associated with occupational stressors and objective executive cognitive functioning, in prior work (64, 65). Lower values correspond to beneficial mental health effects.

Statistics

We conducted all statistical analyses by using the Stata 14.2 software (StataCorp LLC, USA). The significance levels for differences between time periods (before resp. during the Covid-19 pandemic) and between groups were calculated by using Pearson chi-square tests for categorical variables and t-tests for continuous variables (i.e. Table 1-7).

Table 3. The proportion of individuals that responded with "often" or "very often" to the questions: "What was your reason to visit nature areas before resp. during the Covid-19 pandemic?"

	before Covid-19	during Covid-19	difference between before and during Covid - 19	
n=1928	%	%	p <	direction
To be in the fresh air	80.0	80.3	0.716	-
To recover from stress	36.0	33.8	0.028	↓
For physical activity	69.7	72.1	0.028	↑
To experience silence/nature sounds	45.9	38.8	0.001	↓
For social reasons	22.0	21.3	0.456	-
To see other people	11.9	14.6	0.001	↑
To walk my dog (or other pet)	12.8	12.8	0.317	-
To relax	62.4	52.5	0.001	↓
To enjoy the beauty of nature	64.8	58.7	0.001	↓
To be alone	18.6	15.7	0.001	↓

For spiritual experiences	8.5	8.7	0.651	-
Because somebody else told me to do that	3.2	3.6	0.225	-
Because it is good for my health	68.8	72.5	0.001	↑
To clear my head/think clearly	37.1	35.0	0.016	↓
Because my work requires it	3.1	3.4	0.331	-
Because it's part of my regular transportation route	10.5	8.0	0.001	↓

Table 4. The proportion of individuals responding with "often" or "very often" to an alternative of the question: "What kind of natural areas did you visit before resp. during the Covid-19 pandemic?"

	difference between			
	before Covid-19	during Covid-19	before and during Covid -19	
n=1928	%	%	p <	direction
Private garden	40.0	41.3	0.046	↑
Park	43.7	39.8	0.016	↓
Forest	51.5	52.6	0.274	-
Freshwater bodies of water	41.8	39.6	0.020	↓
Saltwater beach/boating	16.8	15.5	0.020	↓
Nature reserve	27.0	29.3	0.003	↑
Green play parks	15.6	14.2	0.039	↓

Table 5. Alcohol intake in the study population during the pre-pandemic resp. pandemic period

	n	Mean weekly consumption (in glasses)		Difference between before and during Covid -19		Individuals above the low risk level (%)*		Difference between before and during Covid -19	
		before Covid-19	during Covid-19	p	direction	before Covid-19	during Covid-19	p	direction
<b>Total</b>	2025	3.83	3.95	0.022	↑	13.80	15.70	0.000	↑
<b>Sex</b>									
Men	903	4.48	4.66	0.036	↑	7.60	9.90	0.001	↑
Women	1122	3.32	3.38	0.276	-	18.80	20.40	0.034	↑
<b>Age group</b>									
< 70 years	1658	3.67	3.79	0.005	↑	13.30	15.10	0.002	↑
≥ 70 years	367	4.55	4.71	0.180	-	16.30	18.40	0.032	↑
<b>Education</b>									
primary	110	3.81	2.64	0.436	-	14.40	13.50	0.320	-
secondary	546	3.97	4.03	0.554	-	12.30	15.60	0.001	↑
higher	1122	3.76	3.93	0.008	↑	14.30	15.90	0.014	↑

\* The threshold for individuals above the "low risk" level is >10 glasses/week for men and >7 glasses/week for women

Table 6. The average weekly sitting scores

<i>Subgroup</i>	<i>n</i>	<b>Mean sitting score</b>		<b>Between period difference</b>		
		before Covid-19	during Covid-19	difference	<i>p</i> <	direction
<i>Sex</i>						
<i>men</i>	889	6.7	7.3	0.6	0.001	↑
<i>women</i>	1111	6.6	7.1	0.5	0.001	↑
<i>Age group</i>						
<i>&lt; 70 years</i>	1642	6.9	7.5	0.5	0.001	↑
<i>≥ 70 years</i>	345	5.4	5.9	0.5	0.001	↑
<i>Country of birth</i>						
<i>SSB</i>	1780	6.7	7.2	0.5	0.001	↑
<i>outside SSB</i>	214	6.7	7.4	0.7	0.001	↑
<i>Education</i>						
<i>primary</i>	105	5.1	5.8	0.7	0.006	↑
<i>secondary</i>	537	6.4	7.0	0.6	0.001	↑
<i>higher</i>	1350	6.9	7.4	0.5	0.001	↑
<i>Neighbourhood walkability (tertials)</i>						
<i>poor</i>	628	6.6	7.2	0.6	0.001	↑
<i>good</i>	656	6.6	7.2	0.5	0.001	↑
<i>very good</i>	704	6.7	7.2	0.5	0.001	↑
<i>NDVI within 50m</i>						
<i>low (0-0.29)</i>	373	6.6	7.2	0.5	0.001	↑
<i>average (0.3-0.49)</i>	901	6.8	7.3	0.5	0.001	↑
<i>high (0.5-1)</i>	726	6.5	7.0	0.5	0.001	↑

Table 7. Average values of the mental health estimates stratified by NDVI exposure levels below resp. above the median level within 50 m buffers (CI – Confidence Interval).

<b>Mental health estimate</b>	<b>Average score (CI 95%) at below median NDVI</b>	<b>Average score (CI 95%) at above median NDVI</b>	<b><i>p</i> &lt;</b>	<b>Cronbach's Alpha*</b>
<b>Mental health score (RAND36)</b>	71.82 (70.735;72.905)	73.007 (71.949;74.065)	0.124	0.833
<b>Vitality score (RAND36)</b>	60.093 (58.839;61.347)	61.116 (59.864;62.368)	0.257	0.833
<b>Anxiety score (SCL90)</b>	1.231 (1.129;1.333)	1.115 (1.023;1.206)	0.096	N/A**
<b>Depression score (SCL90)</b>	5.906 (5.58;6.232)	5.68 (5.377;5.984)	0.320	0.900
<b>Perceived Stress Scale (PSS)</b>	8.732 (8.469;8.996)	8.477 (8.229;8.724)	0.166	0.755
<b>The Cognitive Stress Score (COPSOQ)</b>	31.55 (30.279;32.821)	30.626 (29.352;31.901)	0.314	0.888

\* Cronbach's Alpha for the outcome scale

\*\* Cronbach's Alpha not available as the estimate consisted of two questions only

The associations between NDVI and the mental health outcomes were investigated by linear regression models, estimating beta coefficients ( $\beta$ ) and 95 % confidence intervals (95 % CI). We used the stepwise forward regression modelling approach, based on change-in-estimates criteria, to identify covariates to include in the models. In the final model, covariates associated with the outcome at the 0.1 significance level were included (66). These covariates were: age, sex, income, alcohol consumption (during the pandemic), physical inactivity (during pandemic), and the neighbourhood walkability index. The estimate of education was not associated with any of the mental health outcomes ( $p > 0.5$  in all cases) and was therefore excluded from the final model. Models were fitted for each mental health outcome separately. The linearity of the associations

between NDVI exposure and mental health estimates was investigated through both visual observations of the graphically depicted mental health estimate and NDVI association, and by restricted cubic spline (RCS) linear regression models with three knots positioned according to the Harrell's recommended percentiles (67) on the NDVI scale in the 50m buffer. The models with and without the RCS were compared using the log likelihood test for model fit. While the fully adjusted models in general showed a good fit for linear models (the curvilinear values did not appear significant), the visual examination of the original graphically depicted association between a mental health estimate and NDVI suggested a possible change in direction in the association somewhere in the range of  $0.45 \leq \text{NDVI} \leq 0.50$ . Thus, we also decided to explore the associations by using two separate linear spline models with a knot at an NDVI value of 0.45 and 0.5 respectively. The significance level was set at  $p < 0.05$  in all multivariate analyses estimating the association between NDVI and the respective outcomes.

## Results

### Descriptive statistics, general

The general background statistics are shown in Table 1. The median NDVI exposures within 50m, 100m, 300m and 500m buffers were 0.44, 0.45, 0.47, and 0.46 respectively. No differences regarding the NDVI exposure within 50m buffers were detected in association to sex and age group. High income and education, as well as high walkability tended to be more likely at low NDVI values. High alcohol consumption was more likely at low NDVI values. Being born in Sweden or in the rest of the Scandinavia and the Baltic States increased the likelihood of living in a greener area compared to having any other country of birth. The frequency of people that visit natural areas "often" was higher at high neighbourhood NDVI levels, and having a high sitting score, was less likely at high NDVI exposure.

### Frequency of nature visits pre-pandemic versus during the pandemic.

In average the percentage of people that reported that they visit natural areas "often" in our study population, was 13 percentage points higher during the Covid-19 pandemic than before the pandemic ( $t = -14.78$ ,  $p < 0.0001$ ; Table 2). Further analyses showed that this increase in the frequency of nature visits occurred in almost all population subgroups independently of age, sex, education, ethnic origin, neighbourhood walkability and the NDVI estimates (Table 2). However, this increase was six percentage points higher in the population younger than 70 years than in the population that were 70-years or older (confidence interval (CI) 95 % 1.5, 10.4;  $p \leq 0.009$ ), 10.7 percentage points higher in individuals with higher education than in those with primary education (CI 95 % 3.1, 18.4;  $p \leq 0.006$ ), and 5.8 percentage points higher in the population born in Sweden or in other Scandinavian/ Baltic countries compared to the population born elsewhere (CI 95 % 0.2, 11.4;  $p \leq 0.0411$ ) (Supplementary material B; Table 1S. for all between group differences).

There were no significant differences in the responses to the questions: "What was your reason, before the Covid-19 pandemic, not to visit nature areas more often?" and "What was your reason, during the Covid-19 pandemic, not to visit nature areas more often?" (Supplementary material B; Table 2S).

The proportion of individuals that responded with "often" or "very often" to the questions: "What was your reason to visit nature areas before the Covid-19 pandemic versus during the Covid-19 pandemic?", as well as the direction of the between period differences is reported in the Table 3. The proportion of people that often visited natural areas for physical activity, for seeing other people and because it was good for their health was significantly higher during the pandemic than before the pandemic. The proportion of the study population that reported that they often visited nature areas for reasons such as: to recover from stress, to experience silence/nature sounds, to relax, to

enjoy the beauty of nature, to be alone, to clear my head/think clearly and because it's part of my regular transportation route, was significantly lower for the during-pandemic period than for the before the pandemic period. There were no significant between-period differences concerning the response alternatives: to be in the fresh air, for social reasons, for spiritual experiences, because somebody else told me to do that, and because my work requires it.

The proportion of individuals that responded with "often" or "very often" to an alternative of the question: "What kind of natural areas did you visit before resp. during the Covid-19 pandemic?" are shown in Table 4. According to our data, the use of private gardens and nature reserves was significantly higher, and the use of the parks, freshwater bodies, beaches and green play parks significantly lower during the pandemic than before the pandemic. The use of forests did not show any significant changes.

#### Alcohol intake in the study population pre-pandemic resp. during the pandemic

The average weekly consumption of alcohol was significantly higher during the pandemic than before the pandemic in the total sample as well as in several subgroups (see Table 5.). The percentage of individuals with daily alcohol intakes above the low risk level were significantly higher during the pandemic than before the pandemic in almost all the subgroups (Table 5).

#### Sitting score

The average weekly sitting scores were reported to be significantly higher during the Covid-19 pandemic than before the pandemic in all subgroups (Table 6). We did not find any significant between-group differences in the percentage points of change.

#### Associations between NDVI and the mental health estimates

The mental health estimates did not differ between the individuals that were exposed to NDVI levels (within 50m buffers) below versus above the median (Table 7). However, when the NDVI exposure was stratified by walkability measures (either below or above the median levels), the mental health estimates significantly differed between the high and low NDVI exposure groups, but only when the walkability was low (Supplementary material B; Table 3S).

No mental health estimates were associated with NDVI in the non-adjusted models or in models only adjusted for sex and age (Supplementary material B; Table 4S). The results of the fully adjusted models are shown in Table 8 (for 50m buffers, including the estimates for all covariates) and in Figure 1 (corresponding numerical values are shown in the Table 5S in the Supplementary material B). In fully adjusted models, increased NDVI was associated with better mental health regardless of the estimate; however, the effect and significance levels differed between different buffer sizes. While the Mental Health and Anxiety scores showed significant associations with the NDVI values at smaller buffer sizes (i.e. 50m and 100m), the association with Depression and Vitality scores as well as with the Perceived stress Scale were significant only at larger buffer sizes (300m and/or 500m). The association between the Cognitive Stress Scale and NDVI was significant at all buffer sizes. Income and walkability appeared to be the covariates with the largest confounding effect in all cases and were positively associated with the mental health estimates. Being male, older, born in Sweden, as well as having low physical inactivity score, consuming alcohol below the "low risk" level and visiting natural areas "often" were generally associated with better mental health.

Table 8. Association between NDVI within 50m and the mental health estimates – fully adjusted model (\*p<0.05; CI – Confidence Interval).

<i>Variable name</i>	<b>Mental health score (RAND36) β (95% CI)</b>	<b>Vitality (RAND36)</b>	<b>Anxiety score (SCL90)</b>	<b>Depression score (SCL90)</b>	<b>Perceived Stress Scale (PSS)</b>	<b>The Cognitive Stress Score (COPSOQ)</b>
<i>NDVI 50m</i>	5.951 (0.688;11.213)* 0.199 (0.136;0.261)*	4.842 (-1.219;10.902) 0.222 (0.15;0.294)*	-0.615 (-1.095;-0.136)* -0.016 (-0.021;-0.01)*	-1.331 (-2.889;0.227) -0.056 (-0.074;-0.037)*	-1.202 (-2.465;0.061) -0.042 (-0.057;-0.027)*	-6.307 (-12.604;-0.01)* -0.149 (-0.224;-0.074)*
<i>Sex</i>						
<i>male</i>	ref.	ref.	ref.	ref.	ref.	ref.
<i>female</i>	-2.419 (-3.92;-0.919)* 0.253 (0.203;0.303)*	-2.44 (-4.168;-0.711)* 0.303 (0.246;0.361)*	0.146 (0.009;0.283)* -0.024 (-0.029;-0.019)*	0.461 (0.016;0.905)* -0.066 (-0.081;-0.051)*	0.586 (0.225;0.946)* -0.069 (-0.081;-0.057)*	3.033 (1.236;4.83)* -0.309 (-0.369;-0.249)*
<i>Age</i>	1.548 (1.1;1.995)* -0.554 (-0.791;-0.317)*	1.448 (0.933;1.964)* -0.952 (-1.225;-0.68)*	-0.156 (-0.197;-0.115)* 0.04 (0.018;0.061)*	-0.55 (-0.682;-0.417)* 0.204 (0.133;0.274)*	-0.249 (-0.357;-0.141)* 0.065 (0.008;0.122)*	-1.735 (-2.271;-1.199)* 0.577 (0.294;0.86)*
<i>Physical inactivity</i>						
<i>Frequency of nature visits</i>						
<i>seldom</i>	ref.	ref.	ref.	ref.	ref.	ref.
<i>often</i>	3.638 (1.811;5.466)*	6.685 (4.581;8.79)*	-0.157 (-0.323;0.01)	-1.004 (-1.545;-0.464)*	-0.617 (-1.055;-0.178)*	-2.6 (-4.784;-0.417)*
<i>Place of birth</i>						
<i>Sweden</i>	ref.	ref.	ref.	ref.	ref.	ref.
<i>other SBC</i>	1.577 (-1.975;5.129) -4.415 (-7.861;-0.97)*	2.351 (-1.739;6.442) -3.159 (-7.126;0.809)	0.03 (-0.294;0.354) 0.457 (0.144;0.769)*	-0.714 (-1.766;0.338) 0.465 (-0.55;1.481)	0.007 (-0.852;0.865) 1.578 (0.746;2.41)*	-2.854 (-7.109;1.4) 2.726 (-1.379;6.831)
<i>rest of the Europe</i>	-2.963 (-6.159;0.233)	-2.907 (-6.587;0.774)	0.397 (0.105;0.688)*	0.515 (-0.432;1.461)	1.148 (0.383;1.912)*	0.731 (-3.097;4.558)
<i>rest of the world</i>						
<i>Alcohol consumption</i>						
<i>below the risk level</i>	ref.	ref.	ref.	ref.	ref.	ref.
<i>above the risk level</i>	-3.09 (-5.105;-1.076)*	-3.449 (-5.769;-1.129)*	0.155 (-0.029;0.338)	1.018 (0.421;1.615)*	0.663 (0.178;1.148)*	1.459 (-0.957;3.874)

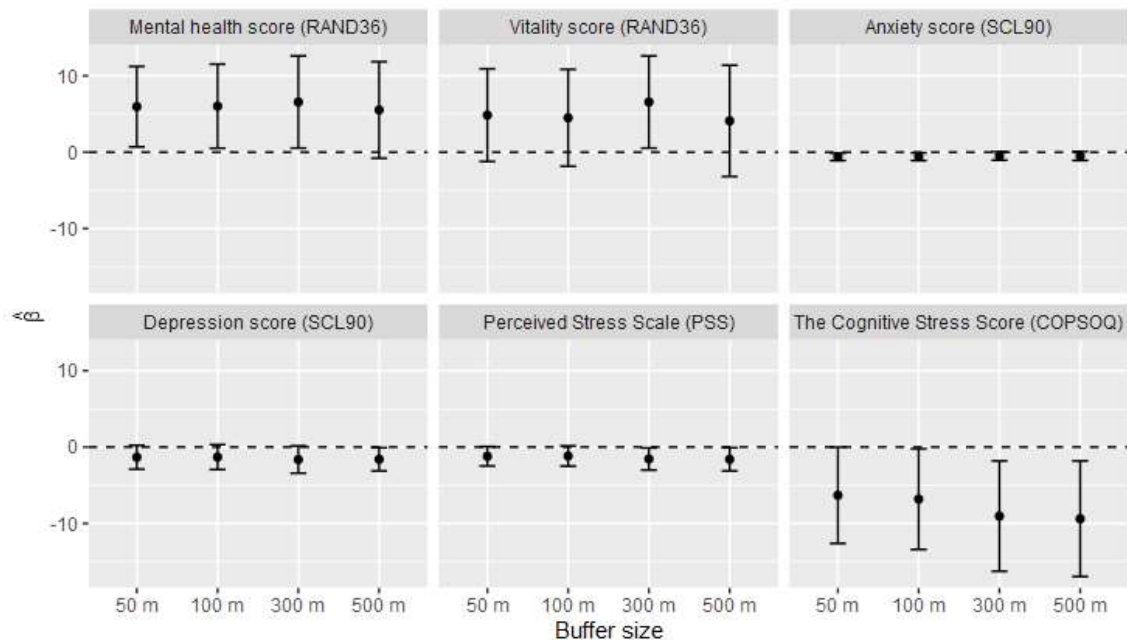


Figure 1. Mental health estimates associated with NDVI within different buffer sizes (models adjusted as in table 6). (95% CI)

The linear spline models with the knot at a NDVI value of either 0.45 (Figure 2.) or 0.5 (Supplementary material B; Table 6S) revealed a pattern according to which only the NDVI values above the knot value were significantly associated with the mental health estimates.

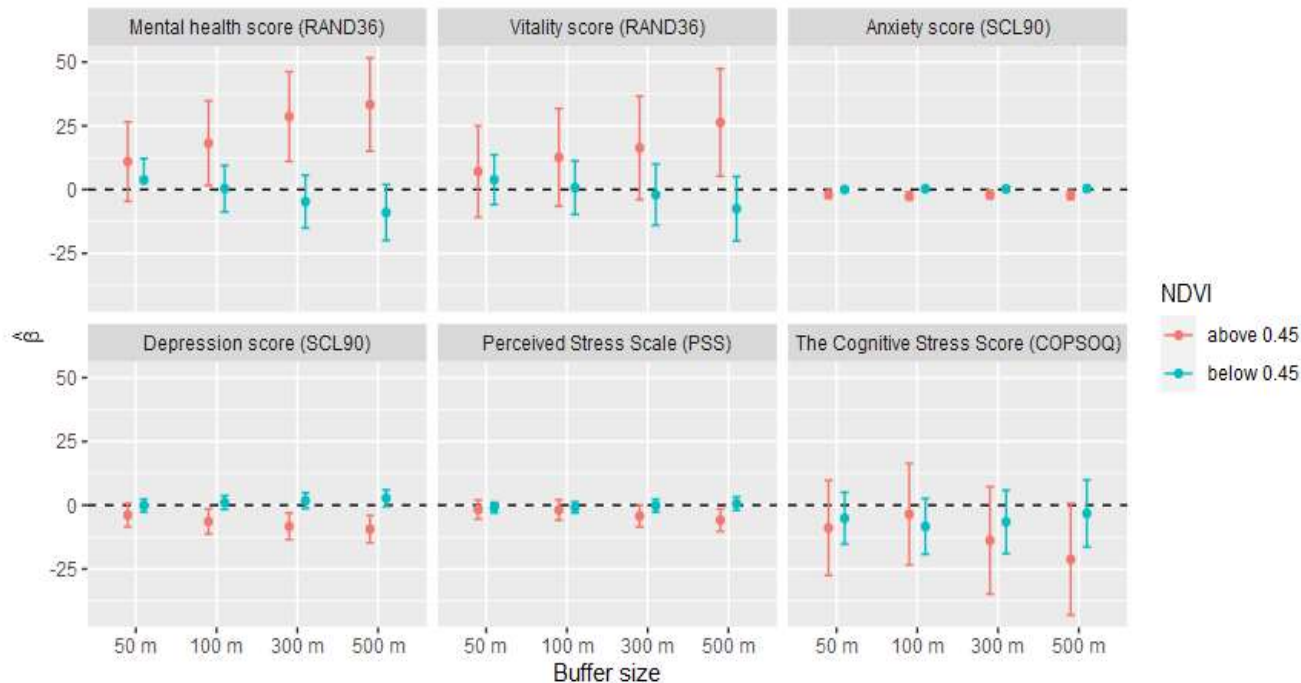


Figure 2. Mental health estimates associated with NDVI within different buffer sizes (models adjusted as in table 6). Fully adjusted linear spline models with the knot set to NDVI = 0.45 (95% CI)

## Discussion

The number of individuals that reported that they visited natural areas “often” was significantly higher during the pandemic than before the pandemic in all population subgroups. However, this increase was significantly higher among those who were younger than 70 years (compared to those being older than 70 years), had university education (compared to the primary education) and were born in Sweden or in other Scandinavian/Baltic countries (compared to those born elsewhere). Visits to nature reserves and private gardens increased significantly during the pandemic, while visits to parks, water-related areas and green play-parks decreased. The number of individuals with alcohol consumption above the “low-risk level” increased significantly during the pandemic compared to prior to the pandemic. High levels of greenness surrounding one’s location of residence were associated with better mental health in almost all mental health estimates analysed in this study, after adjustments for demographic variables and walkability. Being female, physically inactive, born outside Sweden/rest of the Nordic countries and consuming alcohol above the low-risk level was generally associated with lower mental health estimates. Higher age, walkability index, annual income, and visiting natural areas “often” was associated with better mental health.

Our study is largely in agreement with the findings from the previous studies. For example, two recent publications – from Japan and Bulgaria – have reported that increased frequency of green area use and/or increased access to green views through the windows at home during the Covid-19 pandemic-related restrictions were associated with positive mental health effects (2, 10). In the present study, we did not investigate the effect of the green window views; however, we believe that using (among others) the rather small buffer sizes (such as 50m surrounding the place of residence) did reflect the relative difference in the quantity of greenness that people were able to see through their windows. Generally, while the wellbeing-mental health (RAND36), vitality (RAND36) and anxiety (SCL90) scores in our study showed significant associations with the surrounding greenness when the buffer sizes were small (50m and 100m), the relationships between greenness and depression (SCL90), as well as between greenness and perceived stress scale (PSS) scores were significant only at larger buffer sizes (300m and 500m). This may indicate a difference in the mechanistic pathways regarding the relationship between various mental health estimates and greenness. It is possible that while in some cases the positive health effect may be a result of passively viewing nature, in other cases it could be related to physical activity and movement in the surrounding areas. The cognitive stress scores showed a significant relationship with the surrounding greenness at all buffer sizes. This corresponds to previous findings on the positive impact of nature interactions as well as neighbourhood greenness on cognitive functioning (24, 30).

A multinational survey, including responses from 77 different countries, found that while the pandemic-related lockdowns significantly affected mental health, the contact with nature helped people to cope with these impacts (31). Furthermore, the positive effect of nature was especially obvious in countries with strict lockdown restrictions. The nature of the mental health estimation tools, used in our study, does not allow any retroactive analyses of the mental health, thus we were not able to analyse the change in the mental health between the periods of before the pandemic and during the pandemic. However, the effect of greenness on the mental health estimates showed a constant positive trend in the fully adjusted models, and this relationship was further strengthened by the self-reported high frequency of the nature visits.

We did not find any associations between the mental health outcomes and neighbourhood greenness levels in our unadjusted models. This result was not surprising for several reasons. Socioeconomic status is known to be positively related to mental health (68-70), while the levels of neighbourhood greenness may also differ depending on the socioeconomic factors (71, 72). In a previous study, we found that in Stockholm County the direction of the association between area level greenness and socio-economy show opposite trends, depending on the type of the municipality in focus (73). Generally, the central urban areas with high socioeconomic status have relatively low levels of greenness (compared to the urban areas with low socio-economy); while in the suburbs, areas with low socio-economic status have lower greenness levels (compared to suburban areas with

high socio-economy). The municipalities that were included to the present study did differ in their degree of urbanisation, which is (based on the opposite directional associations described above) likely to counteract the appearance of any obvious mental health-greenness trends in the unadjusted models. The walkability indexes, based on self-reported responses, strongly reflected the degree of area urbanisation (Supplementary material C ). In groups exposed to higher neighbourhood walkability, as well as higher income, the positive association between neighbourhood greenness and mental health was profoundly stronger.

Our investigative approach to use linear spline models with a knot at a NDVI value of 0.45 (based on visual observations of the relationships between mental health scores and NDVI values ) revealed a pattern according to which only the NDVI values above the knot value were significantly associated with the mental health estimates. One possible interpretation of this is that the quantity of greenness only affects mental health above a specific (and in this case, rather high) threshold value. However, as the NDVI values are lowest in central Stockholm, where the socioeconomic status of the residents is rather high (and higher socioeconomic status shows a positive relationship with the mental health estimates), this could simply be an effect of the location-specific differences in the interactions between the levels of greenness, socio-economy and the mental health scores. Since no other studies have previously used this approach, we are unable to compare our results to the data from others.

The participants of the present study reported that they visited natural areas significantly more often during the spring of the pandemic than they would have been expected to do if the pandemic had not happened. The use of the private gardens (including privately owned summerhouses) was reported to have significantly increased during the pandemic compared to before the pandemic period. This is not surprising, as using gardens is among the easiest and safest ways to get away from the indoor environment without the need of encountering general public. Private gardens may also have provided opportunities for physical activity (for example, in form of gardening work) for people that avoided visiting gyms or other sport facilities because of the covid-19 pandemic (many of these facilities in Sweden were open for public use during the spring 2020, however the degree of use decreased markedly, especially among the elderly).

A recent study from Oslo, Norway reported intensified activity of both pedestrians and cyclist on trails with higher greenness during the Covid-restrictions on the spring 2020 (50). Furthermore, the trail use was affected by the trail accessibility and social distancing preferences, as the trail remoteness significantly increased the use of a trail (50). These results partly reflect our findings. The participants in the present study reported that they visited nature reserves more frequently during the pandemic than before the pandemic. Since nature reserves tend to generally be found in more remote locations than other dedicated urban green areas, it may reflect the tendency of people to find places where the risk of encountering others is low. In opposite to the studies from Norway (50) and Germany (49), where the authors also found increased pedestrian activity in the city parks and peri-urban forests, the participants of the present study reported that they visited parks less often during the pandemic than before the pandemic, while the frequency of forest visits did not change. Since these studies used different methods to register the indications of the movements of the people (mobile tracking (50), interviews (49), and here, self-reported questioners), the data is not comparable as such, and is in our case, strongly dependent on the characteristics of the population group that chose to respond to the questionnaire. However, several of the participants in the present study had in the free text commented that they did not feel secure when outside because of the pandemic, which could partly explain why people chose to visit areas farther from the crowds.

The reasons that were reported for not visiting natural areas did not differ between the pre- and during-pandemic period. However, significantly more people reported that they visited natural areas for physical activity, for seeing other people and because it is good for their health during the pandemic than before the pandemic. Significantly fewer individuals reported that they visited natural areas to recover from stress, to experience silence/nature sounds, to relax, to enjoy the beauty of nature, to be alone, to clear their head/think clearly and because it is part of their regular transportation route during the pandemic than before the pandemic. It is likely, that rather than the

population of Stockholm County losing their ability to enjoy the sounds and beauty of nature these responses reflect a change of focus during the pandemic. Being able to experience the existence of other individuals, as well as having an opportunity for physical activity may have become more important during this time-period characterized by decreased social interactions, increased time spent sitting and restricted access to sporting facilities/activities than the aesthetics of nature. Furthermore, since many chose to work from home, the number of people that visited natural areas because it was part of their regular transportation route was expected to decrease.

There has been a growing concern in the literature that the pandemic-related social isolation may lead to an increase in alcohol consumption and/or abuse (74-77). Several researches have pointed out that the stress associated with increased loneliness and potential economic difficulties or domestic relationship problems may serve as significant triggers for alcohol use and may lead to an increase in the prevalence of alcohol use disorder and alcohol-related harms (75, 77-79). In our present study, we found indications of increased alcohol consumption during the pandemic. Especially individuals of male sex and younger than 70-years seemed to have significantly increased their weekly alcohol intake. It might therefore be important to acknowledge the potential impact of alcohol-related problems associated to the Covid-19 pandemic, and discuss the necessary strategies, which would help the societies to cope with these problems. These could include precautionary measures, like providing support for coping with the stress and social isolation. However, it might also be necessary for healthcare institutions to prepare for an increase in the demand for their services due to alcohol-related problems (75).

Urbanisation has declined human contact with nature but increased the potential of the spread of pandemics (80, 81). Previous studies have reported the health benefits of visiting natural areas (82) and the capacity of nature to buffer the negative health effects in people suffering from social isolation (83) or other stressful life events (20). Thus, we agree with the conclusion of i.e. Soga et al (2) and Pouso et al (31) that urban nature can be used as a nature-based solution for improved public health. Our study, together with the results from others may help decision makers to increase their preparedness for possible long-term effects of the Covid-19 pandemic as well as to mitigate the negative effects of future lockdown strategies by ensuring that people have access to nearby greenery and in this way increasing their resilience when suffering by stress or social isolation.

Some limitations should be considered when interpreting the results from our study. All presented data, except for the objectively estimated NDVI values, was self-reported. Since the data sampling was cross-sectional, we chose to make inquiries about certain behaviours for both the pre-pandemic and during-pandemic periods. This design gave us an opportunity to discover the potential changes in the behaviours; however, we are aware of that recall-bias may have affected the registered responses. Due to the limited time to conduct the study, we decided to only send out the recruiting letters once, but approach a rather large number of people (10 000 individuals). According to our previous experience, a response frequency of about 15 % was expected. Despite that, the actual response frequency (about 20 %) slightly exceeded our expectation; the large majority of our sample (randomly chosen within pre-decided municipalities) did not respond. This was likely to influence the composition of the sample with a bias towards responses from people interested in nature and with overrepresentation of highly educated individuals and people with good socio-economy.

## Conclusions

Our study provided evidence that contact with nature may be important for mental health in extreme circumstances. The Covid-19 related societal restrictions affected the behaviour of the population of Stockholm County by increasing the frequency of nature visits, but also leading to increased alcohol consumption and more hours spent sitting still. Neighbourhood-level greenness seems to affect several aspects of the psychological well-being, especially in combination with good walkability.

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Software: ML, TL, AL

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Investigation: ML, CUDS, TL

Resources: AG, ML, CUDL

Data Curation: ML, TL

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Writing – Review & Editing: ML, CUDS, TL, AL, AG

Visualization: ML, CUDS, TL, AL, AG

Supervision: N/A

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## Institutional Review Board Statement

The study was approved by the Swedish Ethical Review Authority – Dnr: 2019-01011 and Dnr: 2020-02450

## Informed Consent Statement

Informed consent was obtained from all subjects involved in the study

## Conflict of interest

The authors declare no conflict of interest

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