Using social media data to understand the impact of the COVID-19 pandemic on urban green space use

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ABSTRACT

Having access to and visiting urban green space (UGS) improves liveability and provides considerable benefits to residents. However, traditional methods of investigating UGS visitation, such as questionnaires and social surveys, are usually time- and resource-intensive, and frequently provide less transferable, site-specific outcomes. This study uses social media data (Twitter) to examine spatio-temporal changes in UGS use in London associated with COVID-19 related lockdowns. It compares georeferenced Tweets posted in a 3 month period from 23 March to 23 June for 3 years covering the first lockdown in the UK in 2020, with Tweets for the same period in 2019 and 2021. The results show that (1) the land-use type of Public Park and Garden was the most frequently visited type of UGS, which may be correlated with these UGS areas remaining opening during the lockdown period; (2) the usage of UGS decreased in central London and increased in other areas during lockdown, which may correlated with working from home restrictions; (3) activities were positively associated with Physical activities maybe as a result of allowing people to take a single daily exercise, and (4) people spent more time in UGS areas on weekdays than weekends compared to pre-lockdown. This is the first study to examine social media data over consistent time period before, during and after the lockdown in relation to UGS. The results show that the findings and method can inform policy makers in their management and planning of UGS, especially in a period of social crisis like the COVID-19 pandemic.

1. Introduction

Coronavirus Disease 2019 (COVID-19) (Zu et al., 2020) was recognized as a global pandemic by the World Health Organization (WHO) on March 12, 2020 (Dashraath et al., 2020). In response many countries including the United Kingdom adopted a series of public health measures, such as travel restrictions, quarantine, closing non-essential businesses and services, and requiring citizens to stay at home except for essential trips, to mitigate the virus spread (Cameron-Blake et al., 2020). In addition, citizens in the UK had to respect social distancing of 2 m, and wear face coverings when entering shops and using public transport (Shoari et al., 2020). In this lockdown, public mental and physical health were affected by these restriction measures (Erdönmez and Atmiş, 2021; Gao et al., 2020). For example, complaints of musculoskeletal and circulatory system disorders increased during the lockdown, and the separation from relatives and friends caused psychological harm (Erdönmez and Atmiş, 2021). Research has showed that urban parks and green spaces had a significantly positive impact on

individuals' mental and physical health in this period (Theodorou et al., 2021), thus parks and green spaces became increasingly important public places for supporting physical and mental wellbeing (Geng et al., 2021; Zhu and Xu, 2021).

This study investigates the impacts of lockdown on urban green space (UGS) use in London by comparing visits to UGS in the before, during and after the first lockdown period in 2020, as captured through social media (Twitter) following Cui et al. (2021).

UGS refers to urban land covered by vegetation (Niemelä, 1999). It plays a critical role in sustaining urban natural environments and the social systems that use these spaces (Kabisch et al., 2015). UGS is one of the key features associated with urban sustainability, as it enhances the quality of life of urban residents (Chiesura, 2004; Houlden et al., 2019). Publicly accessible urban parks are places of solace, recreation, exercise and community enjoyment, and city residents rely on parks and green spaces for physical, mental, and social wellbeing (Houlden et al., 2019).

Twitter is a free social media (microblogging) platform which allows users to post messages of up to 280 characters in length, with additional

information such as coordinates and time of posting based on user preference (Steiger et al., 2015). The high spatial and temporal resolution provides researchers with opportunities to analyse the spatio-temporal distributions of Tweets as well as their content. Twitter data has already been used successfully in UGS research recently (Cui et al., 2021; Plunz et al., 2019; Roberts, 2017), but has not yet been used to examine the spatio-temporal changes in UGS visitation, during the COVID-19 pandemic period. This study uses geo-referenced Twitter data extracted for 3 coincident period before, during and after the COVID-19 lockdown to examine changes in the spatio-temporal patterns of UGS visitation.

Twitter data covering 23 March to 23 June were extracted for three years (2019, 2020, 2021) for London and used to capture UGS behaviors and to see how UGS behaviors may have been changed by the lockdown restrictions. This research seeks to answer a number of research questions (RQ):

RQ1: What types of UGS were more frequently visited and how did this change?

RQ2: In which area(s) did UGS visitation increase or decrease?

RQ3: How did UGS activities change, if at all?

RQ4: Did the timing of UGS visitation change?

This paper has been organized as follows: Section 2 presents the background and timelines on UK lockdown and restriction measures, as well as related research has explored the impacts of COVID-19 on UGS use. Section 3 presents the dataset and the methodology employed. Section 4 outlines how UGS visitation patterns changed over the three years. Section 5 discusses the results and suggests some areas of further work, before some concluding comments are made (Section 6).

2. Background

2.1. Lockdown rules and restriction measures in the UK

At the outbreak of the COVID-19 pandemic in the UK in early 2020, the government implemented a series of measures in England specifically (Greater London Authority, 2021) to reduce the spread of the disease (Fig. 1) (the rules in the other Scotland, Wales, and Northern Ireland were different).

On 23 March 2020, the UK government announced national lockdown which stated that all residents must stay at home and work from home, with the exception of shopping for basic necessities. Social events were cancelled and shops selling non-essential goods were closed.

Citizens were permitted to take outdoor exercise once per day. Having access to some form of outdoor space such as public parks is vital for people, especially children and those who live in homes without a garden (Poortinga et al., 2021). Fortunately, parks largely remained open, giving people the opportunities to exercise and enjoy fresh air, although gatherings were banned during lockdown. In England citizens were allowed to visit UGS with members of the same households, remaining 2 m (6 ft) away from other people (GOV.UK, 2020b). UGS visitation was also facilitated by the warmer Spring weather in the UK in 2020.

On 24 April 2020, the government encouraged park managers to keep public parks open to support these activities. Approximately 90 % of public parks remained open during the first lockdown in March 2020 (GOV.UK, 2020a) with some restrictions including limiting park opening times, and closing children's play areas and sports facilities. On 13 May 2020, people in England were allowed to spend more time in park areas to exercise, and to enjoy the outdoors. In addition, sports facilities such as tennis courts, golf courses, and basketball courts were reopened, as sport and exercise provide benefits for people's physical and mental health (Fagerholm et al., 2021), and the government encouraged everyone to stay as active as possible. On 20 May, people were allowed to meet one person from another household. On 23 June, the 2 m social distancing restriction was changed to 1 m to enable people to meet their family and friends, and the government announced that the first national lockdown was to end in England.

2.2. The role of UGS during lockdown

UGS has gained an increasing amount of attention in both academic and policy areas, especially to understand how people visit park areas and their perceptions of UGS (Erdönmez and Atmiş, 2021; Zhu and Xu, 2021). During the COVID-19 pandemic, public mental and physical health were influenced by the restriction measures including working from home, quarantine, and by the constant stream of negative news around the pandemic (such as increasing cases and deaths) (Erdönmez and Atmiş, 2021; Gao et al., 2020). Investigations into park usage during lockdown showed significant changes in visitor behavior patterns, and that urban parks and green spaces had a significantly positive impact on individual mental and physical health in this period (Theodorou et al., 2021). However, the few studies that have analysed changes in the spatial and temporal patterns of urban park visitations during the COVID-19 pandemic period, have offered limited insight. Lopez et al. (2021) focused on changes in park visitor numbers but not changes in
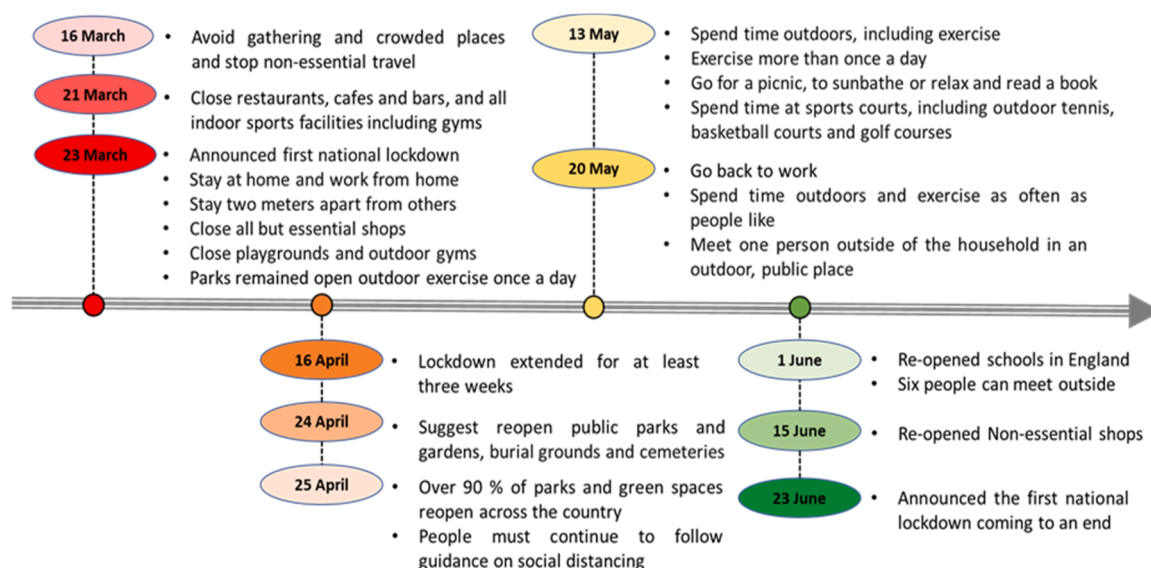

Fig. 1. Timeline of UK restriction measures for COVID-19 during 2020.

spatio-temporal patterns of park visits. Geng et al. (2021) examined changes in people who visited urban parks during the COVID-19 pandemic period but over global, regional, and national scales, rather than local ones. Ugolini et al. (2020) and Erdönmez and Atmiş (2021) explored the impacts of the COVID-19 pandemic on park visits and activities through an online questionnaire, but did not examine the spatio-temporal patterns of park usage during the period. Understanding these patterns may be useful for urban planners and managers especially during a health crisis.

Spatio-temporal analysis of geo-referenced Tweets can provide additional contextual information about the patterns of UGS use and the status of visitors to address RQ (1) 'where', RQ (2) 'what', and RQ (3) 'when'? For example, examining the changes in the spatial patterns of UGS visitation provide information on the actual responses to place-based policy and practice. Changes in the temporal patterns of UGS visitation provide information on how daily routines may have been changed due to restrictions such as working from home and restricting public transport, etc. Geo-referenced Twitter data contains a time-stamp, coordinates, and text information and can be a valuable data source for spatio-temporal analysis (Huang et al., 2018). Thus, in this study, spatio-temporal analysis of geo-referenced Tweets was used to understand the changes in UGS use before, during and after lockdown.

2.3. Social media used to investigate UGS activities

UGS play an essential role in providing physical and social wellbeing for visitors, thus, how to appropriately measure UGS activities is an important research question. For instance, using a questionnaire approach, four types of activities were defined by Sim and Miller (2019): Physical activities, including biking, walking and running; Mental health activities, including relaxing and restoration; Social interaction, including meeting with friends or family, and other activities such as passing the parks. Lesser and Nienhuis (2020) explored how lockdown influenced physical activity during the pandemic but did not examine other types of UGS activities such as social recreational and leisure related ones, despite these representing a large proportion of UGS visits (Sim and Miller, 2019). Social media data have proven to be useful in assessing UGS usage in urban and suburban areas (Cui et al., 2021; Roberts, 2017).

Twitter has become a popular social media platform for many research areas. Tweet data has been used to support land use classifications of urban areas (Mesa-Arango et al., 2016), to investigate emotional responses to different spaces (Zhu and Xu, 2021), to explore how information spreads through urban areas (Huang and Wong, 2016). In order to categorize Twitter posts into specific kinds of park activity, Salloum et al. (2017) used text mining approaches to extract information from unstructured Tweet. Word frequencies were calculated to identify the park activities and the results were used to conduct sentiment analysis. They found that social media data can capture important activities such as 'eating' in parks areas, which could not be distinguished in questionnaire responses. Roberts (2017) extracted information from Twitter data on physical activity in UGS. Tweets were manually screened by authors and word frequencies were calculated for sports-related Tweets, and seven types of physical activity were identified (running, walking, biking, water sports, team sports, and outdoor fitness), demonstrating how Tweets can be used to investigate park physical activities, and to fill the gaps in traditional research methods.

Twitter released a new version of the standard Search Tweets endpoint as part of Twitter Application Programming Interface (API) in 2020. This includes many new features, such as the ability to access the full history of Tweets, allowing researchers to programmatically access public Tweets from the complete archive dating back to March 2006. In this way, the new API provides more complete, and unbiased data than previous Twitter APIs. In the current study, full historical Twitter data were used to explore the impacts of COVID-19 on UGS use, with the aim of assessing the extent to which the government-mandated restriction

measures influenced the use of UGS. It explores different types of UGS and people's activities in UGS areas, as well as variations in the temporal and spatial patterns before, during and after the first lockdown period.

3. Study area and methods

3.1. Twitter data and overview of the analysis

The Twitter datasets used for this study were downloaded via the Twitter academic research API. The API call selected geo-referenced Tweets located in London. They covered a three-month period (23rd March to 23rd Jun) for three consecutive years: 2019, 2020, and 2021. To begin with, the changes in the spatial distributions of geo-located Tweets for three individual years were analysed and the most frequently visited UGSs were identified in each year. Activities in UGS were also identified using text mining (Salloum et al., 2017), and their spatio-temporal changes were investigated. The Twitter data were analyzed over hours and days to identify changes in temporal patterns. A paired sample t-test was used to significant differences between the use of UGS over the three years. All the analyses were undertaken using R software (Ihaka and Gentleman, 1996).

3.2. Study area

The study area is London, UK (Fig. 2), 40 % of which is public green space composed of eight main urban parks and about 3000 smaller urban green spaces covering 23, 599 ha (GiGL, 2019).

In order to detect whether the COVID-19 lockdown restrictions, including working from home had exerted obvious impacts on UGS visitation, the study area was further separated into London's Central Business District (LCBD) and non-LCBD area (Sulis et al., 2018). The major workplaces, businesses, and tourist attractions are located in LCBD, with many people commuting between LCBD and other areas before lockdown.

3.3. Data collection, pre-processing and analysis

Green space in London was derived from the Open Green Space layer from the Ordnance Survey (Ordnance Survey, 2021a). The spatial distribution of green space is shown in Fig. 2. In order to explore the differences of UGS use among various types of UGS, all open green spaces in study area were classified into 10 functional categories (Ordnance Survey, 2021b), based on the criteria in Table 1. The number of Tweets in each type of UGS and their percentages of the total Tweets were calculated.

Text mining was used to analyse the Twitter data. It is an analytical method used by researchers to extract meaningful information (He et al., 2013). Text mining processes include text pre-processing, text representation, and information extraction (Hu and Liu, 2012). Text pre-processing includes stop word removal, lower-casing and stemming. Stop words refer to the most common words in data sets, for example, English words such as "a", "the", "is", "are", etc. Stop word removal deletes all meaningless words in textual data. Transforming text to lower case removes all capitalization and stemming identifies the roots of words. Non-text characters are also removed including punctuation, hashtag, URLs, and numbers before conducting text analysis. In the current study, Twitter data were cleaned in this way to allow topic grouping, sentiment assessment and to identify patterns of user opinions and perceptions. First, duplicated Tweets text from users who posted more than ten times within one day were removed. Tweets posted from bots, fake accounts, and users who posted a same Tweet text more than three times in the data were also removed. Second, only Tweets in English were selected and Tweets with fewer than three words were removed. Third, the Twitter data were cleaned as described above with punctuation, URLs, numbers and stop words removed. The data were converted to lower case and stemmed. The cumulative effects of the
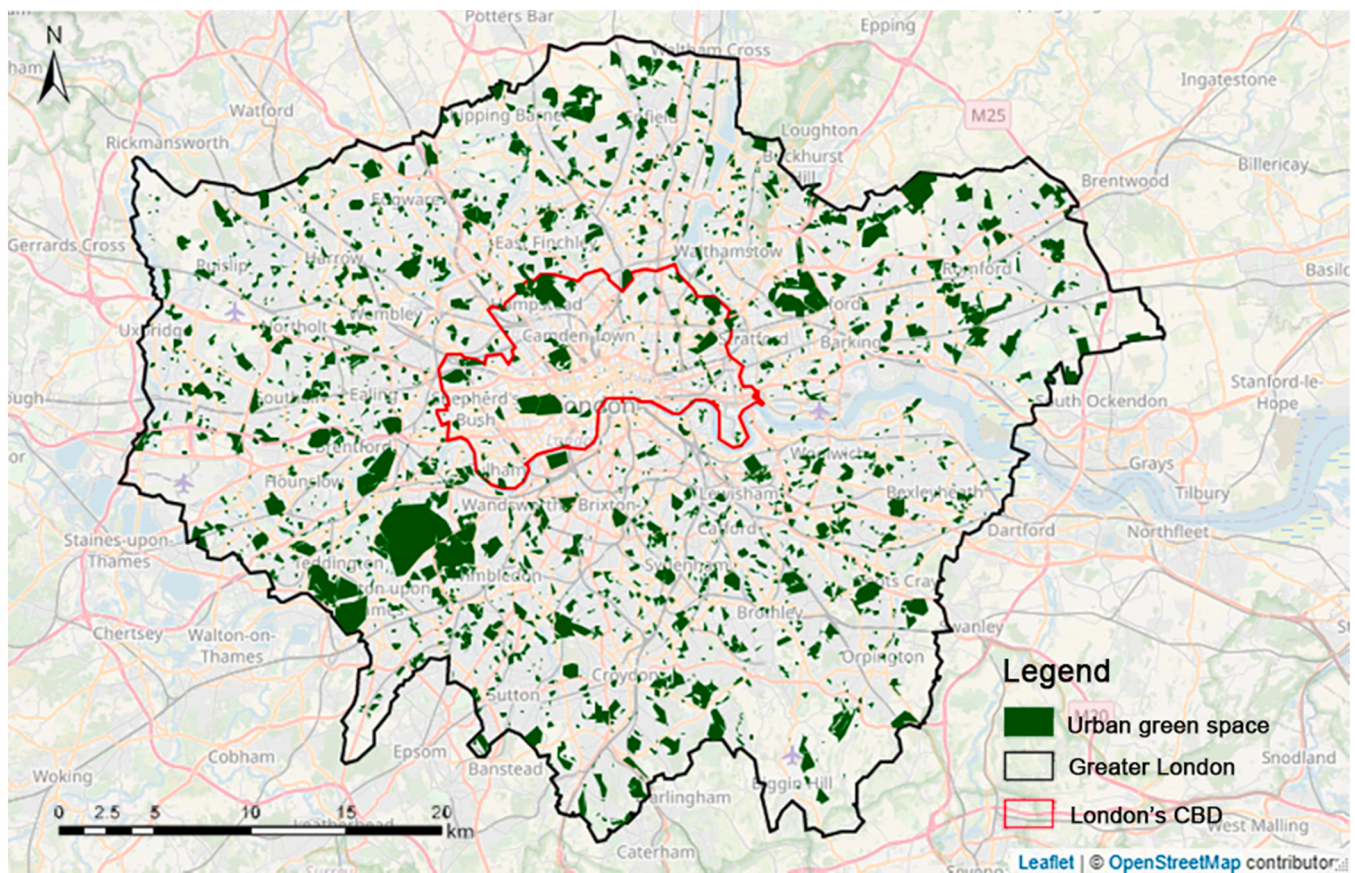
Fig. 2. The distribution of open green space in London.

Table 1
Urban green space classification and corresponding descriptions.

	UGS classification	Description
1	Community Growing Spaces	"the areas of land where plants such as fruits and vegetables are grown, primarily for the demands of the growers themselves, rather than for commercial activities"
2	Bowling Green	"a specially prepared area intended for playing bowls"
3	Cemetery	"the areas of land associated with burial areas"
4	Religious Grounds	"the areas of land associated with churches and other places of worship"
5	Golf Course	"the areas of land that are specially prepared for playing golf".
6	Other Sports Facility	"areas of land that were used for sports and not specifically described by other categories".
7	Play Space	"a specially prepared area intended for children's play, usually linked to housing areas or parks and containing purpose-built equipment".
8	Playing Field	"large, flat areas of grass or specially designed surfaces, generally with marked pitches, used primarily for outdoor sports, i.e. football, rugby, cricket".
9	Public Park or Garden	"areas of land designed, constructed, managed and maintained as a public park or garden. These normally have a defined perimeter and free public access".
10	Tennis Court	"a specially prepared area intended for playing tennis".

Table 2
The numbers of Tweets after each step of the data cleaning.

Process	2019	2020	2021
All collected Geo-Tweets	296,329	207,412	145,019
Tweets from bots, fake accounts removed	284,229	192,535	130,155
Identical Tweets posted more than three times removed	283,682	192,361	129,935
Tweets with fewer than three words removed	271,752	182,666	122,938
Geo-Tweets from London Area	257,050	170,003	112,969
Tweets within urban green space (UGS Tweets)	12,286	8645	5955
Percentages of Tweets in UGS	4.78 %	5.09 %	5.27 %

their home location, which is difficult to use for analysis of spatial dynamics. This is because a user might post several Tweets in different places which are not differentiated by this attribute. Geo-referenced Tweets are key to this kind of analysis.

In order to investigate the impact of the pandemic on UGS activities, this study identified six main groups of UGS activities based on previous studies using questionnaire, observations and text-mining (Lesser and Nienhuis, 2020; Roberts, 2017; Sim and Miller, 2019; Sim et al., 2020). These were physical activity, viewing art, social interactions, leisure, picnics, and exploring nature. The related keywords for each type of activity are shown in Table 3 and Tweets were linked to a specific activity through these keywords. In this way a corpus of Tweets linked to UGS activity for each year was created. All of analyses were undertaken in R (Ihaka and Gentleman, 1996).

An initial exploratory data analysis was undertaken before investigating UGS activities in more detail to understand user behavior when visiting UGS areas. Differences between years the time periods

preprocessing steps on the number of Tweets in 2019, 2020 and 2021 are shown in Table 2. Note that the geo-referenced locations of individual Tweets were used to examine the spatio-temporal patterns of UGS visitation. User profile information includes a static location, usually

Table 3
The keywords used to filter the relevant activities.

Activity	Keywords
Art	"art" "museum" "gallery" "photo" "music" "paint" "show" "dance" "sing" "photographer"
Leisure	"view" "see" "watch" "overlook" "enjoy" "look" "listen" "hear"
Nature	"flower" "tree" "bird" "blossom" "sky" "weather" "animals" "zoo" "goose" "swan"
Physical	"walk" "run" "bike" "football" "jog" "swim" "sport" "marathon" "yoga" "skate"
Picnic	"lunch" "snack" "sandwich" "food" "coffee" "yum" "drinking" "beer" "cake" "brunch"
Social	"party" "festival" "friend" "family" "mom" "dad" "wedding" "father" "mother" "meet"

(2019–2020, 2020–2021, 2019–2021) were explored through paired sample t-tests to investigate whether the impact of COVID-19 restrictions and lockdown rules resulted in differences in changes UGS visitation patterns. The same approach was used to compare differences across UGS types and UGS activities. Finally, the daily and hourly patterns of UGS visitation were investigated to detect whether COVID-19 restrictions influenced the temporal patterns when people visited UGS.

4. Results

4.1. Changes in UGS visitation during pandemic

Table 2 shows the number and percentage of all Tweets in London compared to those in UGS. The total number of Tweets in London continuously decreased from 2019 to 2021, the same trend was found in the number of UGS Tweets. However, the proportion of UGS Tweets slightly increased from 2019 to 2021.

Examining the Tweets located in different types of UGS can help to understand UGS use. Table 4 shows the changes in the number of Tweets located in each kind of UGS. As larger UGSs are likely to contain more Tweets than smaller ones, Tweet density (Tweets per hectare) is included. Overall, 80 % of all Tweets were posted in Public Park Or Garden, Playing Fields in 2020 and a distinct trend of increased visitation in park types related to physical activities was found during lockdown. Public Park Or Garden was the most frequently visited type among all UGS. Playing Fields showed an increasing trend from 2019 to 2021, indicating increased and sustained demands for this type of urban green space over the lockdown periods. The percentages of Tweets in Community Growing Spaces, Bowling Green and Tennis Court were less than 1.00 % in all years. However, downward trends were found in Cemetery, Other Sports Facilities, Play Space, Religious Grounds and Tennis Court from 2019 to 2020, with Other sports facilities, Religious Grounds and Tennis Court increasing in 2021.

Tweet densities show that Bowling Greens had the highest Tweet density: 0.98 in 2019, 0.84 in 2020, and 0.57 in 2021, but with the lowest number of Tweets (93) and the smallest size (95 ha). Public Park and Garden, the UGS with the largest areas, had lower densities of 0.84

(2019), 0.60 (2020), and 0.37 (2021). The lowest density was found in Golf Course: 0.06 in 2019 and 0.04 in 2020 and 0.06 which was the second-lowest in 2021, but with second largest area (4516 ha).

Fig. 3 shows the spatial distributions of UGS visitation in 2019, 2020, and 2021. In 2019, high levels of visitation were mainly concentrated in LCBD and south central London, with lower visitation levels located in the periphery. However, this status appeared to change slightly during lockdown, with UGS use appearing to disperse to some degree especially around the LCBD in 2020 and 2021.

To determine whether the observed changes in UGS use levels were statistically significant, a paired sample t-test was conducted to investigate the changes in UGS visitation levels among the three time periods. Table 5 shows the differences between each time period in all London, LCBD and Non-LCBD. Overall, in the whole study area (London), significant differences were found in Pair 1 (from 2019 to 2020) and Pair 2 (2020–2021), and no significant difference was observed in Pair 3 (2019–2021). The change in the mean value of UGS use levels in Pair 1 (-0.32, $p < 0.05$) shows a significant decrease in 2020 compared to 2019. In contrast, Pair 2 (-0.29, $p < 0.01$) shows a significant increase in 2021 compared to 2020, while in Pair 3 no significant difference was observed between 2019 and 2021, indicating that UGS visitation levels were not significantly different in the before and after the lockdown periods.

Similar trends were found in the LCBD. Significant differences were found in Pair 1 and Pair 3 with changes in UGS visitation levels in LCBD significantly decreased from 2019 to 2020 (-0.86, $p < 0.01$) and to 2021 (-0.63, $p < 0.05$). This indicates that the restriction measures such as working from home, closure of shops, etc. may have significantly influenced the levels of UGS visitation in the LCBD, even though there was an increase from 2020 to 2021.

Opposite trends were found in the non-LCBD. Increasing trends were found across all 3 periods with significant differences in Pair 2 (0.23, $p < 0.05$) and Pair 3 (0.26, $p < 0.05$), indicating that UGS visitation levels continuously increased from 2019 to 2020 and to 2021 in the non-LCBD. The results in Table 5 show that the UGS visitation levels changed from 2019 to 2020, and to 2021.

To further explore the changes in spatial patterns of UGS visitation, the spatial distributions of UGS visitation were investigated. These are shown in Fig. 4. Figs. 4a, b, and 4c show the spatial distributions of increasing trends in the levels of UGS visitation between each pair of years, and decreasing trends are shown in Figs. 4d, e and f.

From 2019–2020, Fig. 4a suggests an increasing trend in UGS visitation outside of LCBD; in the southern part of London and along the northern LCBD boundary. Fig. 4d shows that UGS use within the LCBD broadly decreased, suggesting that UGS use moved away from the centre of the city during the first lockdown in 2020. From 2020–2021, Fig. 4b suggests an increase in UGS use within the LCBD, indicating that UGS visitation levels may have started to return to pre-pandemic levels. This is supported by a decreasing trend (Fig. 4e) that dominates the changes in UGS visitation outside of LCBD. Finally, Fig. 4c, and 4 f compare 2019–2021 and show that although increases in UGS use (Fig. 4c) were
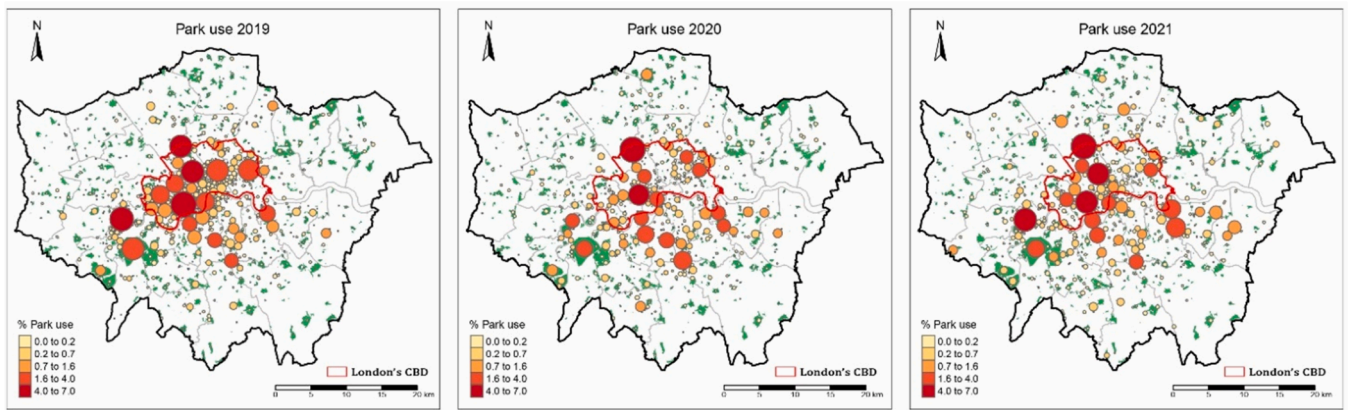
Table 4
Tweets number and Tweets density in different types of UGS.

UGS class		Area (ha)	Number of Tweets						Number of Tweets / ha		
			2019		2020		2021		2019	2020	2021
1	Community Growing Spaces	966	60	0.46 %	53	0.59 %	22	0.36 %	0.06	0.05	0.02
2	Bowling Green	95	93	0.71 %	79	0.88 %	54	0.88 %	0.98	0.84	0.57
3	Cemetery	1251	276	2.11 %	148	1.65 %	96	1.56 %	0.22	0.12	0.08
4	Golf Course	4516	277	2.12 %	195	2.17 %	293	4.77 %	0.06	0.04	0.06
5	Other Sports Facility	2752	806	6.17 %	500	5.57 %	605	9.84 %	0.29	0.18	0.22
6	Play Space	289	191	1.46 %	103	1.15 %	29	0.47 %	0.66	0.36	0.10
7	Playing Field	3263	840	6.43 %	682	7.60 %	523	8.51 %	0.26	0.21	0.16
8	Public Park Or Garden	11,776	9853	75.45 %	7046	78.48 %	4355	70.82 %	0.84	0.60	0.37
9	Religious Grounds	283	546	4.18 %	131	1.46 %	140	2.28 %	1.93	0.46	0.49
10	Tennis Court	190	117	0.90 %	41	0.46 %	32	0.52 %	0.62	0.22	0.17

Fig. 3. Spatial distributions of UGS use in 2019, 2020 and 2021, as a percentage of all Tweets.

Table 5
The changes in UGS visitation across the three years.

	Paired Years	Mean (London)	Sig (p)	Mean (LCBD)	Sig (p)	Mean (Non-LCBD)	Sig (p)
Pair 1	From 2019–2020	- 0.32	0.023 *	-0.86	0.002 * *	+ 0.04	0.736 ns
Pair 2	From 2020–2021	+ 0.29	0.008 * *	+ 0.23	0.074 ns	+ 0.23	0.046 *
Pair 3	From 2019–2021	- 0.03	0.837 ns	-0.63	0.019 *	+ 0.26	0.010 *

Significant differences between the every two groups were identified by the paired samples test and marked by * at p < 0.05, ** at p < 0.01, and ns for no significance.
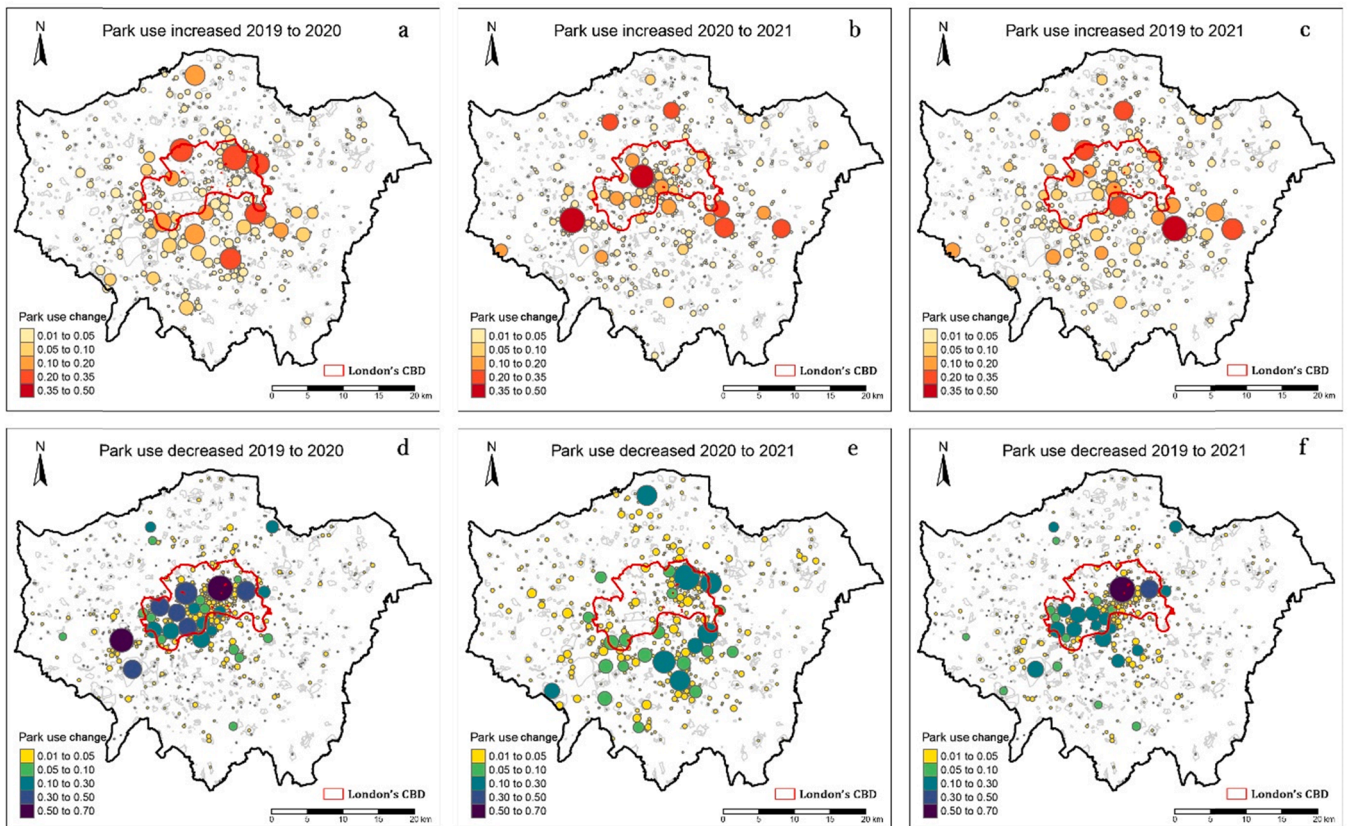

Fig. 4. The spatial changes of UGS use from 2019 to 2020 and 2020–2021 in London.

widely distributed within and without the LCBD, there was a concentrated decline within the LCBD (Fig. 4f). This suggests that overall UGS visitation levels may have increased throughout London, but the central areas were more likely to see a decrease.

4.2. Changes in the temporal patterns of UGS visitation

To investigate the temporal distribution of UGS users, the Tweets were grouped to daily and weekly patterns (Fig. 5). There are obvious differences in the 3 periods. The number of UGS Tweets on weekends
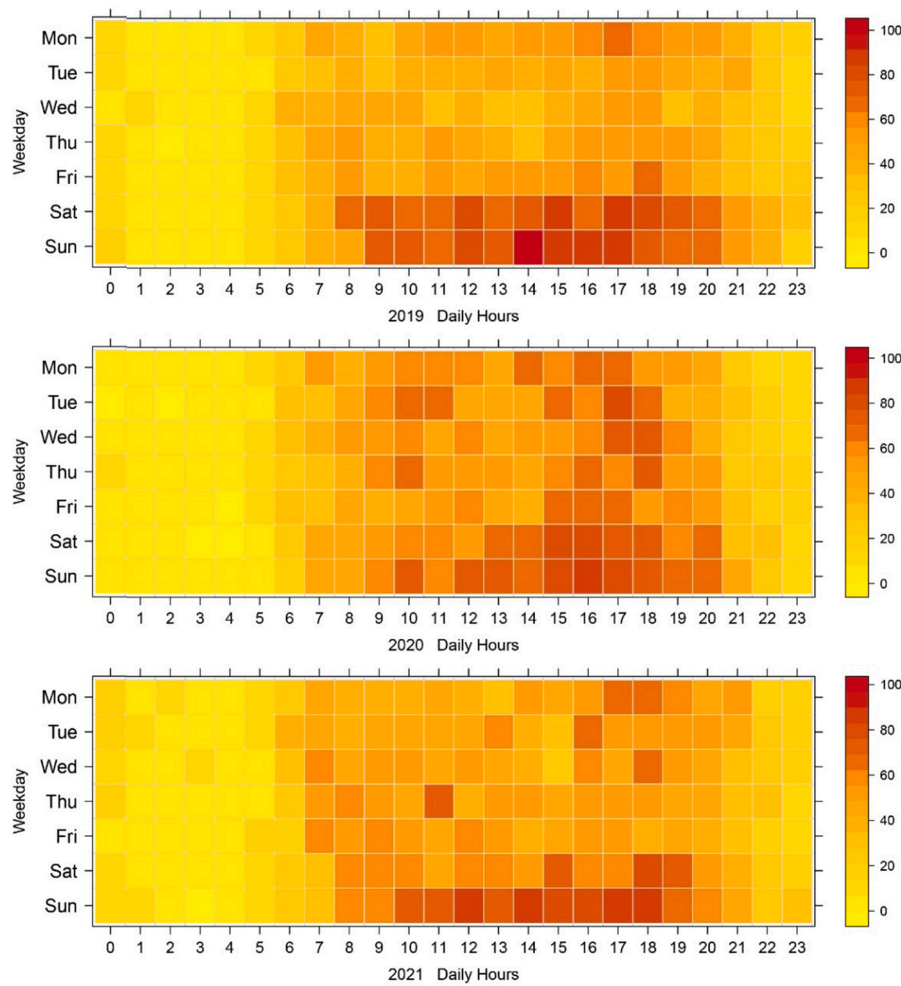
Fig. 5. Daily pattern and hourly pattern of counts of UGS Tweets in 2019, 2020 and 2021.

was much higher than weekdays in the pre-pandemic period (2019). However, there is no significant difference in the number of Tweets on weekdays and weekends in 2020, indicating that UGS were more frequently visited during the pandemic period compared to pre-pandemic period. In 2021, the number of UGS Tweets on Sunday was higher than other days.

When the hourly patterns are examined, there are very few Tweets between 22:00 (10 pm) and 05:00 (5 am), as might be expected across the 3 periods. What is evident is the increased morning and afternoon usage in 2020, especially on weekdays as people either undertook their permitted daily exercise or later in the year used the UGS to socialise, when the weather was generally warm and dry during the spring of 2020 in the UK (time and date, 2021). This may show the result of restrictions on working from home, giving people more flexibility in arranging their daily lives. In 2021, with the beginnings of a return to normal life, the daily UGS visitation pattern was similar to that of 2019, indicating that the UGS in London became important recreational destinations for citizens especially during the pandemic period and people prefer to visit parks and green spaces in the afternoon and evening.

4.3. Changes in UGS activities during lockdown

Table 6 shows the percentages of Tweets in relation to each kind of UGS activity relative to all Tweets in each year. Overall, the total percentages of UGS activity Tweets increased from 80.07 % to 84.26 % and 89.48 % in 2019, 2020 and 2021, respectively, indicating that UGS activities became more frequent during and after the lockdown period.

Table 6

The percentages of activity related Tweets to all Tweets in each year.

Activity	2019	2020	2021
Art	30.49 %	28.66 %	38.38 %
Leisure	8.11 %	8.95 %	16.59 %
Nature	9.65 %	12.16 %	13.27 %
Physical	12.75 %	18.81 %	10.16 %
Picnic	5.99 %	6.40 %	4.11 %
Social	13.08 %	9.28 %	6.97 %
Total	80.07 %	84.26 %	89.48 %

Specifically, the percentages of Art Activity Tweets were the highest among all types of UGS activity across three years, indicating that users were mainly taking photos, visiting galleries, museums, or painting when they visited UGS. The trajectory of Art Activity Tweets (decreased from 2019 to 2020, increased in 2021) may be as a result of restriction measures, for example, outdoor music events were cancelled (Onderdijk et al., 2021) and people were only able to visit UGS once a day during the lockdown period.

The second most participated UGS activity was Social Activity in 2019 (13.08 %), indicating that people may have met their friends or family members when visiting UGS pre lockdown. This showed an evident decline from 2019 to 2020 and 2021 (9.28 % and 6.97 %, respectively), indicating that the restriction rules such as social distancing during lockdown may have exerted impact on Social Activity in UGS areas.

Leisure Activity accounted for 8.11 % in 2019, then increased

slightly to 8.95 % in 2020 and increased more greatly to 16.59 % in 2021, indicating that leisure activities were becoming more frequent after the lockdown. The percentages of Nature activity increased from 2019 to 2021, suggesting that users may be more interested in observing nature during and after the lockdown.

Physical Activity was the third most frequent UGS activity in 2019 (12.75 %) and increased during the lockdown period. It accounted for 18.81 % in 2020, indicating that users preferred running, walking, and other physical exercise during lockdown over other activities. The percentage of Physical Activity decreased to 10.16 % in 2021, indicating that Physical Activity may have played a very important role in people's daily life especially during a pandemic period.

The percentages of Picnic Activity was the lowest across all study periods, indicating that a small part of UGS users were having picnic when they visited UGS before, during and after the first lockdown period.

5. Discussion

5.1. Discussion of results

UGS is widely recognized as an essential component of urban areas, as it provides considerable public health and environmental benefits, especially during difficult times such as the COVID-19 lockdown periods (Ugolini et al., 2020). To our knowledge, full historical Twitter data sets were used for the first time in this study to examine the changes in UGS visitation before, during and after the first lockdown in London. This study explored the potential impacts of COVID-19 on the usage of UGS using Twitter data, and the results demonstrate that this data source could be a reliable proxy for assessing UGS visitation. The findings of this analysis indicate the changes in types of UGS used, the types of activities undertaken and their spatio-temporal patterns in London. This study addressed the following research questions:

RQ1. What types of UGS were more frequently visited and how did this change?

Public Park or Garden and Playing Field were more frequently visited, indicating that the demand for visiting these types of UGS increased during the pandemic period. Other studies have also claimed that the importance of UGS significantly increased during the pandemic (da Schio et al., 2021). For example, Ugolini et al. (2020) found that a large proportion of urban residents missed UGS and would readily travel long distances to access UGS during the pandemic period for basic needs such as fresh air and scenery. However, restriction measures on closing Cemetery, Other Sports Facilities, Play Space, Religious Grounds, and Tennis Court and social distancing may have resulted in their usage during lockdown in 2020. The closure of these types of UGS may have resulted in people changing their UGS destinations and activities, which may increase the possibility of physical and psychological disorders of users (Erdönmez and Atmiş, 2021). In 2021, the percentages of Tweets in Other Sports Facilities, Religious Grounds, and Tennis Court increased, indicating that reopening these UGSs led to a higher frequency of UGS visitation in the period of the post lockdown. Other studies have found fewer psychological disorders in areas where the use of UGS was not prohibited (Freeman and Eykelbosh, 2020), indicating the potential importance of UGS remaining accessible during a health crisis like the COVID-19 pandemic. Future planning could be encouraged to create more spaces for individual activities such as enjoying nature and walking or running freely in UGS (Erdönmez and Atmiş, 2021).

Considering the Tweet number and Tweet density in Table 4 indicates that simply using the number of Tweets in an area is not an appropriate measure to estimate the visitation of UGS and that the number of Tweets by area is universal. By measuring Tweet densities this study found that the frequency of UGS visitation are affected by factors including but not limited to UGS size and the types of UGS. This requires further exploration.

RQ2. In which area(s) did UGS visitation increase or decrease?

Opposite trends were found in the UGS visitation levels in LCBD and non-LCBD areas during the lockdown period. The visitation levels in LCBD decreased compared with pre-lockdown. The lockdown rules resulted in reduced UGS visitation levels within the LCBD area, but the opposite trend was found in non-LCBD areas. The explanation for this was likely to be the restriction of working from home and the closure of all non-essential shops, resulting a decline in the number of workers and customers in LCBD. In a related study using surveys to investigate the changes in spatio-temporal patterns of UGS use over lockdown, Korpilo et al. (2021) in Helsinki, Finland found that usage and recreational activity in the central part of Helsinki decreased during the pandemic. In a study in Oslo, Norway (Venter et al., 2020) found that physical activities such as cycling and walking decreased in the city centre while they increased in the urban periphery. In this study, an increasing trend was found in the UGS visitation in non-LCBD areas. It is likely that people who work from home were be able to spend more time in local parks and greenspaces (Ipsen et al., 2021). Further studies could be conducted to investigate the UGS visitation of other districts outside of LCBD and non-LCBD areas.

RQ3. How did UGS activities change, if at all?

This study showed that Art Activity accounted for the largest proportion of all activities across the three years, even though this decreased during lockdown, indicating that people were taking photos when they visited UGS (this study covered the Spring season). Social Activity decreased during lockdown, indicating that the restriction measures may have resulted in decrease Social Activity because people were practicing social-distancing when they visited UGS. These activities are non-essential which are especially important in times of crisis (Ugolini et al., 2020), and demonstrates that UGSs are fundamentally different from other kinds of urban public spaces such as pubs, theatres, and non-essential stores. Physical Activity became more frequent during lockdown, as more UGS people took exercise during their visits. Other studies using survey methods to explore the impacts of COVID-19 have found that people who more frequently participated in physical exercise during lockdown had better physical and mental health than others (Geng et al., 2021; Lesser and Nienhuis, 2020), and that they found new experiences in natural settings (Korpilo et al., 2021).

RQ4. Did the timing of UGS visitation change?

Different temporal patterns of UGS visitation were found during the lockdown period compared with before and after the first lockdown periods. Specifically, UGS visitation increased in the daytime during the lockdown compared with the before and after the lockdown periods and the frequency of UGS visits on weekdays increased. These changes are likely to be due to different working patterns: in lockdown people worked at home, they had more autonomy and flexibility over their time, they did not have to commute to work and were able to choose when they visited local UGSs in the daytime. This is supported by other research using surveys which found that respondents preferred to visit UGS closer to their house during the lockdown (Ugolini et al., 2020) and that UGS visitation frequencies were greater in daylight hours than in pre-lockdown times (Venter et al., 2020). This may also be linked the increased ability to spend more time with family members, to support each other mentally and physically within the family group through doing some physical or leisure activities together, facilitated by this enhanced flexibility (Pierce et al., 2020).

5.2. Discussion of methods

This is the first study to examine the impact of COVID-19 related lockdowns on behaviours UGS over before, during and after the first lockdown in 2020. Previous studies have selected specific time intervals within a single year to make comparisons between lockdown and pre-lockdown periods, which may introduce problems caused by seasonal weather and climate patterns. For example, Lesser and Nienhuis (2020) selected time intervals from January to February in 2020 as the

'baseline' to detect the influence of COVID-19 which outbreaks from March to summer; da Schio et al. (2021) implemented a survey from April 25th and July 10th to investigate the changes in UGS visitation before, during, and after the 2020 COVID-19 lockdown in Belgium. In the study presented here, the same periods (spring season from March to June in 2019, 2020, and 2021) were selected across the three years, to reduce the impacts of seasonal UGS visitation variations.

This study has several limitations. First, although Twitter data provides much useful information for understanding spatio-temporal changes in UGS use, there is potential for several inherent biases in these datasets (Roberts, 2017; Steiger et al., 2015). For example, information such as age and education background is not available through Twitter metadata (Plunz et al., 2019). This means that the sample of the population used in this analysis is unknown. A further improvement to analyses of social media data users would be determine the demographics of people who visit urban green space areas. For example, it may be possible to infer user age and educational background by examining their profiles. Second, the study considered only periods before, during and after the first lockdown and some restriction measures were still in place during the 2021 period. This study could be extended to include other lockdown periods and to cover times when policies were relaxed, and lockdown restrictions were fully removed. Third, UGS visitation patterns will not only be affected by restriction policies during lockdown, but also by the characteristics of the UGS such as accessibility, size, quality and facilities (Cohen et al., 2010). A further extension would be to examine UGS visitation in relation to the specific characteristics of each. Fourth, people's opinions about UGS were not only directly captured. Twitter data provide a proxy for UGS visitation, attitudes and preferences and Twitter users represent a small proportion of the actual UGS visitors, although the data reflects the increase in people visiting UGS during lockdown as found in other studies (Fagerholm et al., 2021; Ugolini et al., 2020). However, as yet no study has examined social media data over three-time periods to explore the spatio-temporal patterns of UGS use, and this study is one of the first to confirm behavioural shifts during the lockdown period.

There are a number of other methodological suggestions. The potential effects of geo-location errors in Twitter data could be overcome by using a buffer around UGS boundaries (Plunz et al., 2019) and more data could be collected over other periods to explore the impact of the full lockdown release on UGS visitation and the permanency of the changes observed in this study. Future work could also on a deeper understanding of preferences and attitudes around UGS by examining social media content in greater detail, thereby expanding the analysis of the impact of the COVID-19 pandemic on UGS-related perceptions relative to park use, and other factors related to public space.

6. Conclusion

This study examined the impact of the COVID-19 pandemic on UGS visitation in London, UK. This analysis is novel due to its use of the full Twitter archive and is the first to examine a consistent time period before, during and after the lockdown. It shows how geo-referenced Tweets can be used to investigate the spatio-temporal patterns, including those related to UGS visitation. The results identified clear differences in UGS visitation related to types of UGS and to UGS activity, with high levels of visitation in Public Park and Garden over whole study area, as public parks were one of the few places remaining open during lockdown. This suggests that the enhancement of public parks and gardens provision could be considered in future urban planning, but this does not mean other types of UGS are not important. An increasing trend of physical activity was found suggesting that the demands for sport facilities during a time of pandemic increased, and that people preferred to green space settings to do this. More sport facilities could be included within large parks along with flower and wildlife gardens and greater flexibility in pandemic closure policies could be considered. The provision of a variety of UGS services should be re-considered in response to

the change in behaviors and demands that have arisen from the COVID-19 pandemic, as identified in this study and others. Decreasing trend in UGS visitation were found in the London central business district (LCBD), balanced by increases outside of this area, as result of people working from home. They visited UGS at different times of the day on weekdays during the pandemic due to spending more time with their family and being able to be more flexible in their UGS visitation. This suggests that small, highly localised pocket parks and gardens could enhance people's lives and should be considered by policy to support dynamic and flexible UGS access as people work at home more (Venter et al., 2020). This study demonstrates the value and potential of analysis of social media data to understand UGS usage and dynamics and to inform UGS managers and policy-makers, both in normal times and during periods of lockdown. As the potential for situations increases with rapid changes in climate, socio-economic disruptions, expanding global populations etc., such an understanding of how people react could be crucial for planning responses to future crises.

CRediT authorship contribution statement

Nan Cui: Conceptualization, Methodology, Software, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization. **Victoria Houlden**: Writing – review & editing, Supervision. **Nick Malleson**: Conceptualization, Writing – review & editing, Supervision. **Alexis Comber**: Conceptualization, Writing – review & editing, Supervision, Resources, Visualization.

Declaration of Competing Interest

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

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