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The Multifaceted Impact of COVID-19 on Social Media Users' Wellbeing and Relationship With Urban Nature

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As the coronavirus disease 2019 (COVID-19) pandemic has unfolded, the media is increasingly recognizing the value of urban nature, with greenspace use increasing. In cities, where people often lack access to private greenspaces, parks and other urban greenspaces offer opportunities for exercise and physically distanced socializing. Previous research has demonstrated the benefits of urban greenspaces to both physical and mental health, during times of relative stability. Here, we seek to examine how people's responses to greenspace are affected by a global pandemic, which uniquely affects both physical movements and mental wellbeing in the population at large. We compare tweets focused on nature- and greenspace-related keywords and hashtags from March to July 2019 with tweets from the same period in 2020 for metropolitan regions in the United States. We also examine the influence of stay-at-home restrictions in 2020. These posts reinforce findings from conventional survey approaches showing that people's relationship to greenspace is multifaceted. Furthermore, the results of our pre–post analysis of people's outdoor use suggest that the pandemic has had a differential impact on these multifaceted dimensions of people's engagement with nature. By applying a multidimensional construct of wellbeing, we identify *Positive emotion*, *Positive relationships*, and *Meaning* as subfactors of wellbeing that potentially can be increased by urban nature. These findings are important in demonstrating that greenspace in cities played a critical role in individuals' resilience and wellbeing during the early months of the pandemic and highlighting the need for maintaining and expanding access to urban greenspaces in the future, for the benefit of all city residents.

Keywords: wellbeing, socializing, COVID-19 pandemic, urban nature, greenspace, nature connection

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INTRODUCTION

The coronavirus disease 2019 (COVID-19) pandemic is a new type of disturbance in its spatial and temporal reach. At the time of publication, more than 5 million individuals died of COVID-19 worldwide, since November 3, 2019 (World Health Organization, 2021). Physical distancing measures (Perra, 2021), necessary to stem the transmission of airborne illnesses, in particular, uniquely affect people's physical movements (Stockwell et al., 2021) and mental wellbeing (Pfefferbaum and North, 2020; Twenge and Joiner, 2020). Gym closures and other movement constraints from lockdowns contributed to reductions in physical activity, which can in turn affect mental health (Maugeri et al., 2020). As physical health and mental health during the

COVID-19 pandemic are intertwined, quarantine-induced psychosocial stress also affects physical health factors, such as cardiovascular risk burden (Mattioli et al., 2020). Anecdotal evidence suggests that the pandemic and its resultant stressors, including limitations on travel and other recreation activities, have sent people in droves to seek respite in natural spaces. For instance, much has been made of a "mass" urban migration for city dwellers seeking to move to suburban and rural areas with more outdoor space (Whitaker, 2021) and the observed record-breaking visitation rates at public parks (Geng et al., 2021), which in some instances are to the detriment of the physical distancing measures (Wynveen et al., 2021). Some evidence supports benefits to residents' mental and physical health from exposure and access to greenspace in times of stability (Hartig et al., 2014; Kondo et al., 2018), but in the case of a profound disturbance such as the COVID-19 pandemic, little is known about the role greenspaces may play in fostering resilience, wellbeing, and mental health.

Greenspaces have also played roles in individual and community recovery after natural and anthropogenic disturbances. Often after disturbances, greening activities are taken up by communities, as a way to memorialize what is lost, as happened in New York City after September 11 and in New Orleans after Hurricane Katrina (Tidball et al., 2010). Tidball (2012) theorizes the concept of "urgent biophilia", or seeking out nature during a crisis, can act as and activate a source of resilience in postdisaster settings. Place attachment held by individuals can affect individuals' wellbeing and resilience postdisaster. After destructive fires in Australia, a strong attachment to the environment was associated with a reduction in stress, fewer depression and fire-related posttraumatic stress disorder (PTSD) symptoms, and higher resilience, posttraumatic growth, and life satisfaction (Block et al., 2019). With COVID-19 continuing as a pressing stressor, there is a need to examine these relationships among greenspace, behaviors, wellbeing, and individual and community resilience.

Advances in technology have enabled a revolution in data availability about people's attitudes, behaviors, and experiences. Traditional social science methods include interviews, surveys, participant observation, and focus groups; these methods have high reliability and validity but are time-intensive and, aside from surveys, more challenging to implement during social distancing measures imposed by the COVID-19 pandemic. With the advent of "big data", social media can provide crowdsourced, geotagged data about people's experiences and interactions in parks and greenspaces that enable us to study visitor use and experience in new ways (Wilkins et al., 2021). At the same time, rigorous, automated approaches are needed for expanding such analyses when analyzing social media texts (Johnson et al., 2019). Topic modeling, or segmenting text datasets into categories or topics, is one type of approach that enables the examination of social media content as applied to park experiences (Schertz et al., 2018). Standardized lexicons are another form of content analysis increasingly applied to social media texts (Schwartz and Ungar, 2015). In this work, we aimed to understand the impact of the COVID-19 pandemic. Using social media data paired with county-level measures of greenspace, social vulnerability, population density, and stay-at-home orders, we rapidly collected data to examine wellbeing and greenspace relationships with linguistic approaches to tweet content (i.e., a validated wellbeing lexicon and topic modeling) within cities and urbanized areas in the United States (US), in order to examine the following hypotheses:

- H1: Human wellbeing at the county scale (e.g., county-level wellbeing) is associated with the amount of greenspace available in a county, both prepandemic and during the COVID-19 pandemic.
- H1b: Some components of wellbeing are more associated with greenspace during the COVID-19 pandemic than in the prepandemic data period.
- H2: Nature-based topics, particularly those that describe the use of nature to cope with stressors, are more strongly and positively associated with county-level wellbeing than other nature-based topics.

Background

Subjective Wellbeing

Multiple approaches exist to both define and measure subjective wellbeing, with no single definition. The World Health Organization defines mental health as "a state of wellbeing in which the individual realizes his or her own abilities, can cope with the normal stresses of life, can work productively and fruitfully, and is able to make a contribution to his or her community" (World Health Organization, 2005). Rather than defining wellbeing as the lack of negative psychological states, positive psychologists consider wellbeing to be a measure of flourishing (Seligman, 2011). Subjective wellbeing studies have shown a positive correlation between emotional resilience (self-adjustment and recovery from stress) and the restoration of wellbeing and positive emotions (Bonanno, 2004; Pan and Chan, 2007).

One approach for measuring subjective wellbeing is the PERMA model by Martin Seligman (2011, 2018). PERMA is a multidimensional approach to measuring wellbeing, incorporating *Positive emotion* (P), *Engagement* (E—psychological connection to activities or organizations), *Positive relationships* (R—socially integrated, cared about, supported by), *Meaning* (M—belief one's life is valuable, connected to something greater than oneself), and *Accomplishment* (A—progress toward goals, capable of daily activities, having a sense of achievement) (Seligman, 2011). For application, global measures offer little guidance on how to increase level of wellbeing. In contrast, PERMA provides more specific information to better meet wellbeing needs of communities through offering multiple dimensions that may relate in different ways to different phenomena, rather than a coarser measure of overall wellbeing (Kern et al., 2015).

Wellbeing and Greenspace Access and Use

The relationship between wellbeing and greenspace is well-studied, although mechanistic evidence is mixed. Two main theories focus on the causal mechanism for the benefits of greenspace: stress recovery theory (Ulrich et al., 1991)

and attention restoration theory (Kaplan, 1995). Neither of these theories addresses social context (Marselle, 2019). Biophilia's (Wilson, 1993; Tidball, 2012) role in wellbeing is increasingly examined through the concept of nature connectedness (Capaldi et al., 2014; Cleary et al., 2017), alongside self-determination theory (Ryan and Deci, 2000), which differentiates intrinsic and extrinsic motivations. Other explanations for wellbeing/greenspace relationships hypothesize that natural environments are lower in environmental "bads" such as air pollution (MacKerron and Mourato, 2013), and greenspaces encourage positive behaviors (Barton and Pretty, 2010). Being outdoors in greenspace can allow for physical activity and increase social contact, both of which can positively affect psychosocial wellbeing (Fox, 1999; Kawachi and Berkman, 2001; Houlden et al., 2018). Further unpacking this relationship, Barton et al. (2012) found support for higher self-esteem and mood for individuals engaging in green exercise vs. socially focused indoor exercise, highlighting that exercise, nature, and social factors all are critical to wellbeing. In a review of urban greenspace and overall health, Kondo et al. (2018) found positive associations between urban greenspace exposure and attention, mood, and physical activity, but mixed or no association with depression, stress, or physical health factors. Mechanisms that may explain relationships between subjective wellbeing and nature connection include the psychological need of relatedness (in greenspaces, non-human relatedness) and a fostering of intrinsic value around nature, satisfying an innate biophilic need (Cleary et al., 2017).

Increasingly, large-scale datasets, including social media, are used to examine wellbeing/greenspace relationships. In a study of US cities, park quantity was a strong predictor of survey-derived overall wellbeing at the city scale, in part driven by parks' contributions to physical and community wellbeing (Larson et al., 2016). Schwartz et al. (2020) applied sentiment analysis to tweets for 10 major US cities, finding people write happier tweets inside parks as compared with tweets outside of parks. Recent lexicon and data-driven efforts have been developed to examine subjective wellbeing using social media datasets; an early article in this field of work found subjective wellbeing *via* a validated PERMA-weighted lexicon across the United States to be correlated with three nature/outdoor topics (Schwartz et al., 2013). A similar analysis applied Schwartz's PERMA lexicon to Chinese cities, finding a positive relationship between the amounts of greenspace in cities with subjective wellbeing for all cities in the analysis (Zhao et al., 2019). Validation efforts have found the PERMA-weighted lexicon to perform better than other word-based lexicons, but not as well as data-driven methods for automated text analysis, which are emerging (Jaidka et al., 2020). Such big data efforts enable the scale of analyses to readily expand, but also have potential issues with biases that representative surveys do not, such as only certain segments of the broader population can access or choose to use social media (Gruebner et al., 2017).

Nature as Coping Strategy During Disturbances

Greenspace may serve as treatment for populations who experience traumatic events (Poulsen, 2017). When examining relationships among post-traumatic stress disorder (PTSD) symptoms, neighborhood greenness, neighborhood social cohesion, and emotional resilience, Li et al. (2021) found support for emotional resilience to mediate the relationship between greenness and reduced PTSD after Hurricane Harvey. Nature attachment was associated with fewer symptoms of depression and PTSD post-bushfire in Australia (Block et al., 2019). Emotions can become intensified during disasters, leading the everyday and taken-for-granted, like nearby nature, to become of critical importance.

Recent research of the ongoing COVID-19 pandemic has provided further insight into the role of nature in relation to subjective wellbeing (Jackson et al., 2021) and as a coping mechanism (Robinson et al., 2021). Activity changes around nature have also been identified during the pandemic, with increased gardening, hiking, and wildlife watching, along with changes in socializing; activity changes also vary by demographics such as gender, urban/rural location, and employment status (Morse et al., 2020). Greening both indoors and outdoors (Dzhambov et al., 2021) and both in public and private spaces (Poortinga et al., 2021) is associated with higher subjective wellbeing. In addition, greenspace research during the pandemic has highlighted how existing inequities in access to greenspace have been maintained and exacerbated by the pandemic; Burnett et al. (2021) in the United Kingdom and Jay et al. (2021) in the United States point to differential access and use of greenspace as a function of movement restriction through stay-at-home orders during the pandemic. The amount of greenness in a neighborhood also positively affected physical activity during the pandemic (Yang et al., 2021).

To further examine wellbeing/greenspace relationships, we examine the online discourse around nature and greenspace in cities and urbanized regions in the United States before and during the early months of the COVID-19 pandemic. In doing so, we evaluate county-level wellbeing in relationship to nature characteristics and experiences. We apply a validated PERMA-weighted lexicon and topic models to tweets to examine these relationships.

METHODS

We collected tweets with nature- and greenspace-based keywords and hashtags originating in the United States from January 1, 2019, through July 31, 2020 (**Table 1**). These keywords and hashtags were selected *via* a manual, iterative process beginning with the primary search terms of interest (e.g., nature AND park) and expanding by assessing which words and hashtags seem to occur most frequently in tweets that discussed nature and parks. In particular, the seasonal terms were not part of our initial search but rather derived from this iterative process from observing that users talking about outdoor recreation were also quite likely to mention seasonal terms. This methodology ensured that we focused on nature and greenspace conversations in our analysis. We used Python (v3.8.6) and Twitter's Application Programming Interfaces to collect, parse, and preprocess this json dataset (Sanner, 1999). Preprocessing steps include word lemmatization (as an alternative to stemming), stop word and punctuation removal, and deduplication (including omitting retweets). Preprocessing steps utilized the spaCy library (v3.0.0)

TABLE 1 | Nature and greenspace keywords and hashtags included in search parameters for collecting tweets.

Outdoor* AND recreat*
Forest AND recreat*
Outdoor* AND fun
Time AND outdoor*
Natur* AND fun*
Natur* AND recreat*
Park AND natur*
Park AND outdoor*
Park AND natur* AND outside
Walk* AND natur
Trail AND natur*
Trail AND outdoor*

in Python. This led to a corpus of 2,586,435 tweets; we excluded tweets without latitude/longitude or a city location (e.g., state-only location, no location), resulting in 971,968 tweets retained for analysis.

To understand the semantic content contained within the set of tweets, we fit an unsupervised latent Dirichlet allocation (LDA) topic model with 20 topics using the gensim library (v3.8.0) in Python. Topic models are a widely used class of methodologies to infer semantic structure within text corpora (Valdez et al., 2018). The LDA-based topic model used here resulted in a set of 20 topics, which are represented as groups of semantically related words, with each group comprising an idea or "topic". Of the 20 unsupervised topics, we retained the 10 topics for analysis that addressed aspects of nature and/or greenspace we believed to be relevant to the hypotheses being tested (**Table 2**, see **Supplemental Material 1** for most abundant words for all 20 topics). Other emergent topics appeared to be unrelated to nature for the current purposes (e.g., topics about natural hair and beauty) or tangential to the topic of study (e.g., topics about patio furniture). The full set of topics can be explored further *via* the **Supplementary Materials**. To derive topic labels, we reviewed the most characteristic and salient terms for each topic, as well as analyzing the top 30 tweets most representative of each topic by topic proportion. This iterative analysis allowed us to get a sense of the idea or theme each topic touched upon and label it accordingly.

To derive a measure of wellbeing, we also applied the PERMA-weighted lexicon (see Schwartz et al., 2013, 2016) to each tweet. The PERMA lexicon consists of 12,642 terms that have been assigned scores on the negative and positive dimensions of each PERMA category (i.e., *Positive emotion*, *Engagement*, *Positive relationships*, etc.). We then matched the words within each tweet to the PERMA lexicon, finally summing the weight of each relevant word within the tweet for each of the 10 components (negative and positive) of the PERMA model. Individual values for positive and negative components were then standardized using z scores before combining to create overall measures of each subfactor and an overall index of wellbeing, per Zhao et al. (2019), as each component had different ranges.

We then tagged all tweets, with their 10 topic model themes and positive PERMA measures, to county-level data using a geocoded city location or, if available, exact latitude and longitude from individual tweets to US counties (see Schwartz et al., 2013). The majority of tweets occur within cities and/or urbanized areas (**Figure 1**). We joined additional variables to this county-level dataset, including percent conserved greenspace in county (US Geological Survey and Gap Analysis Project, 2020), county-level social vulnerability indices [SVI, Centers for Disease Control and Prevention (CDC), 2018], population density [American Community Survey 5-year 2013-2018, Centers for Disease Control and Prevention (CDC), 2018], and state-level stay-at-home orders during the pandemic (Argonne National Laboratory, 2020). We selected these variables in order to control for variation across counties (county-level social vulnerability, population density) or to examine hypotheses (percent greenspace, stay-at-home orders). The SVI dataset ranges from 0 = lowest vulnerability to 1 = highest vulnerability. Percent conserved was calculated from the Protected Areas Database, including only protected lands that are publicly accessible; these lands could either be public or private lands with conservation easements and public access (US Geological Survey and Gap Analysis Project, 2020). Population density was calculated as the number of people per square mile in a county, using the total population values from the US Census provided in the SVI dataset [Centers for Disease Control and Prevention (CDC), 2018]. Year was coded as a factor. Stay-at-home orders were coded as a 0 (not present) or 1 (present) for tweets' dates that overlapped with stay-at-home order durations by state. Datasets were joined using both ArcGIS Pro [Environmental Systems Research Institute (ESRI), 2019] and R version 3.2.3 (R Core Team, 2015). We compared differences in medians between 2019 and 2020 using the Mann–Whitney U-test in R (R Core Team, 2015); for all topic and wellbeing comparisons, the data had the same distribution for the two years.

Finally, we developed four sets of mixed-effects models regressed against the PERMA index: (1) including all tweets from January 1 to July 31 for the years 2019 and 2020; (2) only including tweets from January 1, 2019, to July 31, 2019; (3a) only including tweets from January 1, 2020, to July 31, 2020, during the early months of the COVID-19 pandemic; and (3b) including stay-at-home orders in the 2020-only model, as these data did not exist for 2019. All model analyses were developed using the lme4 package (Bates et al., 2015) in R version 3.2.3 (R Core Team, 2015). The pandemic tweets model (2020-only, with stay-at-home orders) also was regressed against all five individual subfactors, P—*Positive emotion*, E—*Engagement*, R—*Positive relationships*, M—*Meaning*, and A—*Accomplishments/achievements*. Individual subfactors included both positive and negative aspects. All models included county and week as random effects.

RESULTS

Tweet-Level Analysis

Nature-Themed Topics

Our 10 retained topics addressed various facets of nature and greenspace, including conditions (*Seasonal weather*,

TABLE 2 | Exemplar tweets by retained topic, in order of prevalence.

2019 (Prepandemic)	2020 (During pandemic)
T13: Seasonal weather	
Definitely like spring semester better actually wake light cold body wanna fall semester hella gloomy dark of outside cold of morning bed comfy	*Outside degrees inside degrees today forecast says high heat getting trapped inside feel hotter gotten peak summer looking forward fire season*
Stepped outside warm car literally feels like going snow went warm weather freezing okay cause winter ready lol stay warm	*Bedroom window open smell hear rain outside nice breeze coming love miss alabama summer nights girl south girl*
T7: Socializing outdoors (safely)	
Summer safety tips summer great time kids enjoy different indoor outdoor activities young children teens learn ways kids safe healthy enjoy	*Summer officially 4th July weekend want community members lots fun sun encourage safe enjoying outdoor activities check seizure safety*
Summer activities plan pet beautiful long days ahead place outdoors time planning exciting summer adventures spending time exploring making	*Lots great ways stay fit active summer aware ways safely getting outside lower risk opportunity enjoy summer sunshine fun stay safe*
T6: Nature appreciation	
Heart filled omnipresence nature shall life filled love words true love exists fall love earth divine love	*Meditation walks nature beautiful music brings love joy bliss etc. consciously moment focus living love heart know need love light*
Choose memories things choose peace stress choose nature hustle bustle city choose love ones choose instead	*Blessed beautiful heart powerful child god image fall nature warrior extraordinary human respect treat love amazing*
T15: Urban ecology/climate change concern	
People live city urban growth mean nature asks empower cities plan positive natural future read+ blog rt	*Interested role forests storing carbon natural climate solutions talk role forest management working lands*
Biodiversity crisis directly threatens human loss wide variety nature services share agree protect ocean 30 by 30 sea hope save the ocean	*Sheer idea stop planet natural evolution shows huberious species multiple cities ocean species built cities dah*
T12: Birds/wildlife	
Went walk morning Beth baby got big turtle lots little ones Florida get outside turtle	*Went walk tonight usual spot dog seen deer times close good shot tonight got lucky enjoy the world we live in enjoy the small things deer nature*
Little fuzzy babies hatched days ago look big nature spring robin nest bird	*Good morning early birds night owls heard different birds morning hear wonder sun today rain kindergarten rocks remote learning*
T1: Urban nature as amenity	
Immersed natural splendor surrounded water Charleston boasts beautiful wide beaches island offering guests unique experience minutes	*Novel coworking river north building Chicago private offices gorgeous natural light modern amenities historical setting book virtual tour location*
Looking privacy nature miss beautiful river valley property stunning river views rolling hills nature amenities property offer exitdubuque	*Real view midtown Manhattan wollman rink central park manhattan nyc arrandr piaf New York Central park architecture nature*
T19: Hiking/camping/beach/vacation	
Howdeeplures killamarikokanee fishing fish nature fishing life outdoors bassfishing ocean fisherman fly fishing angler kokanee addicts like	*Great trail hikingutah awesome ljtrekker hiking mountains nature adventure outdoors hike forest trail trekking trails Utah adventures wanderlust*
Conquer kyndley adventure coolerbag outdoors hiking camping trails beach paradise summer travel nature California free solo Yosemite climbing	*Raidas_life California favorite hikes hiking hike outdoors California trail traveling hiker traveler scenery Cali girls who hike hiking adventures*
T10: County/state/national park status	
U.S forest service says soon begin repairs land lakes national recreation area t	*Joshua tree California south entrance national park Joshua tree south entrance*
Icymi volunteers helped Joshua tree national park open shutdown desert park close	*Great outdoor spaces historic national road Washington county md open recreation*
T11: Outdoor events	
Set ready today gumbo limbo park pm gumbo limbo environmental center nature complex	*Outdoor fun continues august free person programs park details registration arlingtonva*
Officially start summer hours today museum open Monday Saturday p.m. Sunday p.m. kiddie land outdoor rides open Wednesday Sunday	*Fun learn history muscoot farm nature centers Saturday Jan times details my Westchester*
T18: Gardening	
Spring blooming backyard flowers flowerstagram garden gardening beauty nature natural bloom zinnia	*Grow elderberries super easy visit elderberry elderberries herbs garden gardens home gordening flowers landscaping nature diy flower summer*
Flower dirt flowers flower socialenvy petal petals nature beautiful love pretty plants blossom sopretty spring summer flowerstagram	*Cozy British house colorful garden spring home gardens nature flower*

County/state/national park status), activities (*Socializing outdoors*, *Hiking/camping/beach/vacation*, *Outdoor events*, and *Gardening*), experiences (*Nature appreciation*, *Birds/wildlife*), values (*Urban nature as amenity*), and concerns (*Urban ecology/climate change concerns*) (**Table 2**). *Seasonal weather*, which comprised seasonal terms such as "summer," "winter," "spring," and "fall," was the most prevalent nature-related topic at 9.83%. *Socializing outdoors* (8.95%), which comprised terms such as "time," "outdoors," "summer," "fun," and *Nature appreciation* (6.57%), with terms such as "nature," "love," "life," "walk," were

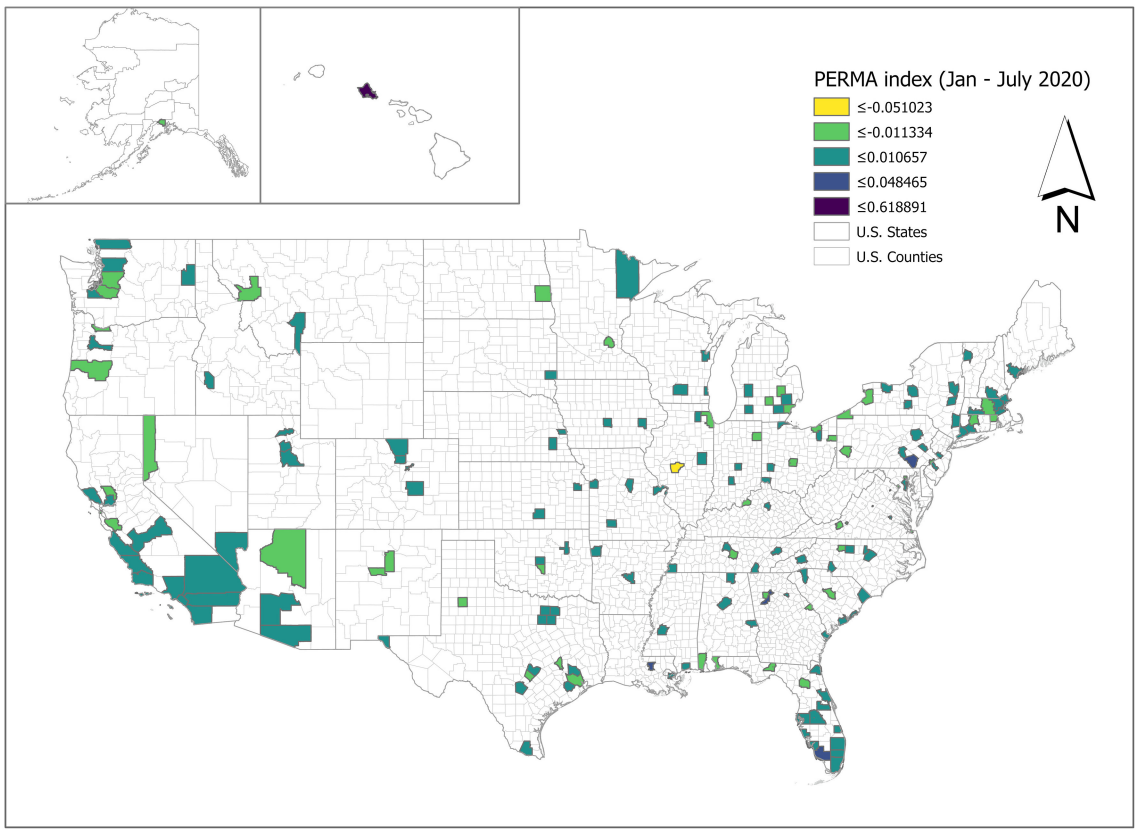

FIGURE 1 | Overall PERMA index for counties with $n \geq 300$ tweets (January to July 2020).

the next most prevalent. The topic labeled *Outdoor events* (4.44%), made up of terms such as "join," "outdoor," "p.m.," "summer," and *Gardening* (3.92%), with terms such as "garden," "spring," "nature," and "flower," were the least prevalent of the nature-related tweets (**Table 3**). Overall, nature-themed topics occurred in 60.4% of the overall tweet dataset.

Plotting topics over 2019 and 2020 revealed both similar and different trajectories of topics across time. For example, the topic labeled *Seasonal weather* showed a distinct cyclic pattern, peaking in early spring in both 2019 and 2020, although the peak was somewhat dampened in 2020 as the onset of the pandemic became clearer. Topics about socializing outdoors increased over time and became more prevalent in 2020, as compared with 2019. Similarly, the *nature appreciation* and *birds/wildlife* topics also increased over the analytic period and became significantly more prevalent in 2020 as compared with 2019, as did the topic about safely socializing outdoors (**Figure 2**).

We also observed topic prevalence to differ between years for all 10 topics, with 2020 seeing an increase in *Nature appreciation* (Mann–Whitney *U*-test, $W = 1.1537 + e^{11}$, $p < 0.00001$) and *Birds/wildlife* ($W = 1.2291 + e^{11}$, $p < 0.00001$) topics. We also observed *Socializing outdoors (safely)* ($W = 1.2146 + e^{11}$, $p < 0.00001$) to increase in discussion during 2020, in comparison with 2019. Activities described in tweets align with nature-based activities also varied among the two years, with *Gardening* increasing ($W = 1.2419 + e^{11}$, $p < 0.00001$) and *Hiking/camping/beach/vacation* decreasing ($W = 1.1737 + e^{11}$, $p < 0.0001$).

Subjective Wellbeing

Plotting the overall PERMA index and individual subfactors identified differences in wellbeing between 2019 and 2020 (**Figure 3**). For all measures, values in 2019 were higher at the same point in time in 2020, and overall, values were consistently higher in 2019 than 2020. In 2019, the overall PERMA index was highest in April and May, whereas it was lowest in March and April in 2020 (between years comparison, Mann–Whitney *U*-test, $W = 1.2471 + e^{11}$, $p < 0.00001$). Individual subfactors vary somewhat over time between January and July for both years, with *Accomplishment* at a high during April and May in 2019 and relatively flat in 2020, with a slight increase in June and July (between years comparison, $W = 1.2424 + e^{11}$, $p < 0.00001$). Positive emotion was higher in 2019 than 2020, with February through April 2020 slightly lower than other months in 2020 (between years comparison, $W = 1.2499 + e^{11}$, $p < 0.00001$). Engagement was higher in 2019 than 2020, with 2020 seeing a slight increase after May 2020 and during this time period, *Engagement* was higher than other subfactors of PERMA (between years comparison, $W = 1.2171 + e^{11}$, $p < 0.00001$). *Positive relationships* and *Meaning* increased over time in 2019 before flattening out in May 2019 and they both saw a slight reduction after January 2020, remaining relatively even through

TABLE 3 | Topic prevalence and top 10 words for nature-themed topics.

Topics	Prevalence	Word 1	Word 2	Word 3	Word 4	Word 5	Word 6	Word 7	Word 8	Word 9	Word 10
T13: Seasonal weather	9.83%	Outside	Summer	Winter	Spring	Like	Fall	Weather	Hot	Day	Cold
T7: Socializing outdoors (safely)	8.95%	Time	Outdoors	Outdoor	Summer	Fun	Great	Enjoy	Family	Kids	Day
T6: Nature appreciation	6.57%	Nature	Life	Love	Walk	World	Find	Walks	Things	Mother	God
T15: Urban ecology/climate change concern	5.97%	Natural	City	Nature	People	Water	Urban	Forest	Gas	Help	New
T12: Birds/wildlife	5.82%	Nature	Walk	Today	Day	Morning	Birds	Wildlife	Beautiful	Little	Trail
T1: Urban nature as amenity	5.52%	Park	City	New	Natural	River	Lake	Outdoor	Area	North	Home
T19: Hiking/camping/beach/vacation	4.66%	Nature	Outdoors	Hiking	Adventure	Hike	Travel	Lake	Ocean	Beach	Camping
T10: County/state/national park status	4.55%	Park	National	State	Recreation	Parks	Nature	Tree	Public	Closed	County
T11: Outdoor events	4.44%	Join	Outdoor	Pm	Summer	Free	Saturday	Park	Today	Day	June
T18: Gardening	3.92%	Garden	Spring	Nature	Flowers	Plants	Backyard	Flower	Gardening	Green	Plant

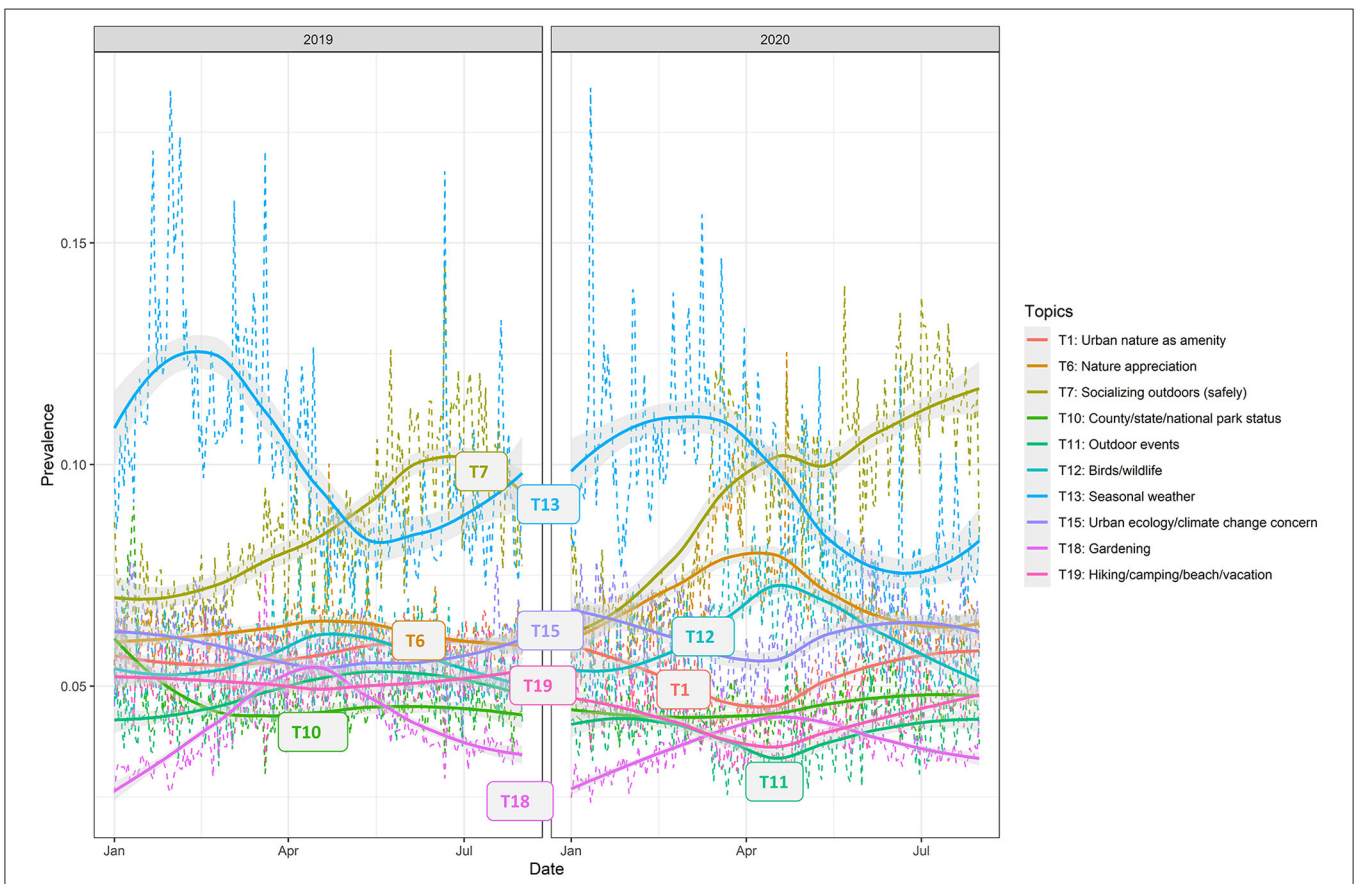

FIGURE 2 | Prevalence of nature-based topics within Twitter dataset in 2019 and 2020.

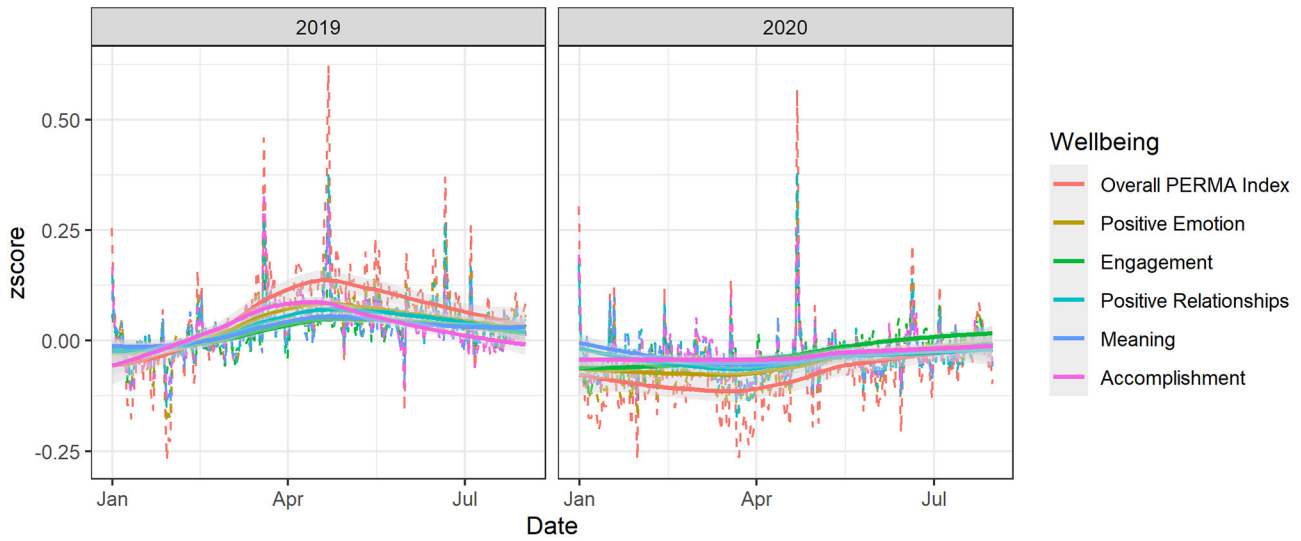

FIGURE 3 | Overall PERMA and individual subfactors during 2019 and 2020, as measured from Twitter dataset.

July 2020 (between years comparison, *Positive relationships*: $W = 1.2454 + e^{11}$, $p < 0.00001$; *Meaning*: $W = 1.2328 + e^{11}$, $p < 0.00001$).

County-Level Analysis

For our mixed-effects models, variance inflation factors were <3 for all independent variables across all models, indicating no presence of multicollinearity. Analyzing residuals for spatial correlation with Moran's *I* found no evidence of spatial autocorrelation. Model results are presented with unstandardized β coefficients; β coefficients for all topics are all on the same scale so effect size can be readily compared within and across models.

Overall PERMA Index

Our mixed-effects model results that included all tweets for 2019 and 2020 show a decline in PERMA from 2019 to 2020 (**Table 4**). Across all models, percent conserved greenspace is positively associated with PERMA (**Table 4**) and subfactors of PERMA in 2020 (**Table 5**), supporting H1. Controlling for year, we also observe all nature-focused topics to be significant, with varying β coefficients between 2019 and 2020, supporting H2. We find positive relationships with the PERMA index for topics 1, 6, 7, 11, 12, 18, and 19 in both 2019 and 2020, supporting H2, with increases in the β coefficient in the 2020 model, particularly for topic 1: *Urban nature as amenity* (from 0.27 to 0.39), 6: *Nature appreciation* (from 0.49 to 0.64), topic 12: *Birds/wildlife* (from 0.43 to 0.64), topic 18: *Gardening* (from 0.20 to 0.49), and topic 19: *Hiking/camping/beach/vacation* (from 0.14 to 0.31). Topic 10: *County/state/national park status* was negatively associated with PERMA in 2019, but positively associated in 2020. Topic 13: *Seasonal weather* was negatively associated with the PERMA index in both 2019 and 2020 models, but to a lesser extent in 2020 (from –0.16 to –0.04). Social vulnerability and population density, included as control variables, were not associated with county-level subjective wellbeing in this dataset.

We also examined associations between wellbeing and stay-at-home orders, finding no relationship for the overall PERMA index during 2020.

Individual Subfactors of PERMA

In examining these same independent variables with the individual subfactors of PERMA for 2020, we find some further nuances and differences in these relationships that support H1b (**Table 5**). Associations between nature-focused topics and PERMA subfactors identify differences in how certain topics are associated with subjective wellbeing, through a comparison of β coefficients from identical, individual subfactor mixed-effects models with the overall PERMA mixed-effects model (**Figure 4**). For example, topic 12: *Birds/wildlife* has a higher β coefficient in the positive *Relationships* and *Positive* emotions subfactor models as compared with the overall index model (set as 0), with topic 12 having the smallest association with the *Engagement* aspect of PERMA.

Percent greenspace has a positive association with all subfactors of PERMA, supporting H1 (**Table 5**). In these subfactor models, we now find a negative effect of stay-at-home orders on subjective wellbeing, finding a negative association for *Positive emotion*, *Positive relationships*, and *Meaning*, but not *Engagement* or *Achievement*. Like the PERMA index models, we find no effect of SVI or population density on subfactors of PERMA.

DISCUSSION

Our work contributes to the ongoing discussion of wellbeing and greenspace, finding nuanced relationships among nature-focused themes on social media in relation to wellbeing. Examining a multidimensional model of wellbeing, PERMA, enables us to examine multiple possible pathways for nature and greenspace

TABLE 4 | Mixed-effects model results for overall PERMA index for (a) 2019 and 2020 tweets, (b) 2019-only tweets, (c) 2020-only tweets, and (d) 2020-only tweets including stay-at-home orders, reporting 95% confidence intervals (CI).

	PERMA index (2019–2020)			PERMA index (2019)			PERMA index (2020)			PERMA index (2020 including stay-at-home)		
Predictors	**β**	**95% CI**	***p***	**β**	**95% CI**	***p***	**β**	**95% CI**	***p***	**β**	**95% CI**	***p***
(Intercept)	−0.15	−0.17 to −0.13	< 0.001	−0.11	−0.13 to −0.10	< 0.001	−0.24	−0.27 to −0.22	< 0.001	−0.24	−0.27 to −0.22	< 0.001
T1: Urban nature as amenity	0.33	0.32 to 0.34	< 0.001	0.27	0.25 to 0.29	< 0.001	0.39	0.37 to 0.41	< 0.001	0.39	0.37 to 0.41	< 0.001
T6: Nature appreciation	0.56	0.55 to 0.57	< 0.001	0.49	0.48 to 0.51	< 0.001	0.64	0.62 to 0.65	< 0.001	0.64	0.63 to 0.66	< 0.001
T7: Socializing outdoors (safely)	1.04	1.03 to 1.05	< 0.001	1.03	1.02 to 1.05	< 0.001	1.06	1.05 to 1.07	< 0.001	1.06	1.05 to 1.07	< 0.001
T10: County/state/national park status	−0.02	−0.04 to −0.01	0.004	−0.08	−0.10 to −0.06	< 0.001	0.06	0.03 to 0.08	< 0.001	0.06	0.03 to 0.08	< 0.001
T11: Outdoor events	0.48	0.46 to 0.49	< 0.001	0.45	0.43 to 0.47	< 0.001	0.48	0.45 to 0.50	< 0.001	0.48	0.45 to 0.51	< 0.001
T12: Birds/wildlife	0.54	0.52 to 0.55	< 0.001	0.43	0.41 to 0.45	< 0.001	0.64	0.62 to 0.66	< 0.001	0.64	0.62 to 0.66	< 0.001
T13: Seasonal weather	−0.10	−0.11 to −0.10	< 0.001	−0.16	−0.17 to −0.15	< 0.001	−0.04	−0.05 to −0.03	< 0.001	−0.04	−0.06 to −0.03	< 0.001
T15: Urban ecology/climate change concern	−0.29	−0.30 to −0.27	< 0.001	−0.37	−0.39 to −0.35	< 0.001	−0.20	−0.22 to −0.18	< 0.001	−0.20	−0.22 to −0.18	< 0.001
T18: Gardening	0.34	0.32 to 0.35	< 0.001	0.20	0.17 to 0.22	< 0.001	0.49	0.47 to 0.52	< 0.001	0.50	0.47 to 0.52	< 0.001
T19: Hiking/camping/beach/vacation	0.22	0.21 to 0.23	< 0.001	0.14	0.12 to 0.16	< 0.001	0.31	0.29 to 0.33	< 0.001	0.30	0.28 to 0.33	< 0.001
Social vulnerability (SVI–SES)	−0.02	−0.05 to 0.02	0.325	−0.02	−0.06 to 0.01	0.142	−0.02	−0.06 to 0.02	0.433	−0.01	−0.06 to 0.03	0.586
Population density (people/sq mi)	−0.00	−0.00 to 0.00	0.791	0.00	−0.00 to 0.00	0.942	−0.00	−0.00 to 0.00	0.505	−0.00	−0.00 to 0.00	0.569
% Conserved	0.00	0.00 to 0.00	< 0.001	0.00	0.00 to 0.00	< 0.001	0.00	0.00 to 0.00	< 0.001	0.00	0.00 to 0.00	< 0.001
Year (2020)	−0.06	−0.06 to −0.06	< 0.001									
Stay-at-home orders in effect (true)										−0.01	−0.01 to 0.00	0.066
Random effects												
σ^2	0.48			0.48			0.47			0.47		
τ_{00}	$0.01_{County.FIPS}$			$0.01_{County.FIPS}$			$0.01_{County.FIPS}$			$0.01_{County.FIPS}$		
	0.00_{week}			0.00_{week}			0.00_{week}			0.00_{week}		
ICC	0.02			0.01			0.02			0.02		
N	$663_{County.FIPS}$			$654_{County.FIPS}$			$653_{County.FIPS}$			$554_{County.FIPS}$		
	31_{week}			31_{week}			31_{week}			31_{week}		
Observations	971,968			505,166			466,802			431,582		
Marginal R^2/conditional R^2	0.074/0.090			0.070/0.082			0.079/0.101			0.079/0.101		

TABLE 5 | Mixed-effects model results for positive subfactors (P—positive emotion, E—engagement, R—positive relationships, M—meaning, and A—accomplishments/achievements) of PERMA for 2020-only tweets, reporting 95% confidence intervals (CI).

	***P* (*z* score)**			***E* (*z* score)**			***R* (*z* score)**			***M* (*z* score)**			***A* (*z* score)**		
Predictors	**β**	**95% CI**	***p***	**β**	**95% CI**	***p***	**β**	**95% CI**	***p***	**β**	**95% CI**	***p***	**β**	**95% CI**	***p***
(Intercept)	−0.27	−0.31 to −0.23	< 0.001	−0.13	−0.15 to −0.10	< 0.001	−0.31	−0.34 to −0.28	< 0.001	−0.28	−0.31 to −0.26	< 0.001	−0.23	−0.26 to −0.21	< 0.001
T1: Urban nature as amenity	0.49	0.47 to 0.52	< 0.001	0.12	0.10 to 0.14	< 0.001	0.50	0.48 to 0.52	< 0.001	0.40	0.38 to 0.42	< 0.001	0.44	0.42 to 0.46	< 0.001
T6: Nature appreciation	0.76	0.74 to 0.78	< 0.001	0.10	0.09 to 0.12	< 0.001	0.75	0.73 to 0.77	< 0.001	1.32	1.30 to 1.33	< 0.001	0.30	0.28 to 0.31	< 0.001
T7: Socializing outdoors (safely)	1.05	1.03 to 1.07	< 0.001	1.11	1.10 to 1.12	< 0.001	1.11	1.09 to 1.12	< 0.001	0.90	0.89 to 0.92	< 0.001	1.13	1.11 to 1.14	< 0.001
T10: County/state/national park status	0.05	0.02 to 0.07	0.001	0.07	0.05 to 0.10	< 0.001	0.17	0.15 to 0.20	< 0.001	−0.05	−0.07 to −0.02	< 0.001	0.03	0.01 to 0.05	0.011
T11: Outdoor events	0.53	0.49 to 0.56	< 0.001	0.44	0.42 to 0.47	< 0.001	0.66	0.63 to 0.69	< 0.001	0.33	0.30 to 0.36	< 0.001	0.44	0.41 to 0.47	< 0.001
T12: Birds/wildlife	0.86	0.84 to 0.88	< 0.001	0.23	0.21 to 0.25	< 0.001	0.99	0.97 to 1.01	< 0.001	0.61	0.59 to 0.63	< 0.001	0.50	0.49 to 0.52	< 0.001
T13: Seasonal weather	−0.07	−0.08 to −0.05	< 0.001	−0.07	−0.09 to −0.06	< 0.001	0.07	0.06 to 0.09	< 0.001	−0.20	−0.21 to −0.18	< 0.001	0.05	0.03 to 0.06	< 0.001
T15: Urban ecology/climate change concern	−0.34	−0.36 to −0.31	< 0.001	−0.40	−0.41 to −0.38	< 0.001	−0.25	−0.27 to −0.23	< 0.001	−0.00	−0.02 to 0.02	0.668	−0.02	−0.04 to −0.00	0.045
T18: Gardening	0.62	0.59 to 0.65	< 0.001	−0.06	−0.08 to −0.03	< 0.001	0.59	0.57 to 0.62	< 0.001	0.71	0.68 to 0.74	< 0.001	0.62	0.59 to 0.64	< 0.001
T19: Hiking/camping/beach/vacation	0.48	0.45 to 0.51	< 0.001	−0.13	−0.15 to −0.11	< 0.001	0.51	0.49 to 0.54	< 0.001	0.48	0.46 to 0.51	< 0.001	0.17	0.15 to 0.19	< 0.001
Social vulnerability (SVI–SES)	−0.03	−0.09 to 0.04	0.406	0.01	−0.04 to 0.05	0.820	−0.04	−0.09 to 0.00	0.075	0.01	−0.04 to 0.05	0.843	−0.01	−0.05 to 0.03	0.741
Population density	−0.00	−0.00 to 0.00	0.655	−0.00	−0.00 to 0.00	0.986	−0.00	−0.00 to 0.00	0.472	−0.00	−0.00 to 0.00	0.538	−0.00	−0.00 to 0.00	0.336
% Conserved	0.00	0.00 to 0.00	0.001	0.00	0.00 to 0.00	0.008	0.00	0.00 to 0.00	< 0.001	0.00	0.00 to 0.00	< 0.001	0.00	0.00 to 0.00	0.007
Stay-at-home orders in effect (true)	−0.01	−0.02 to −0.01	0.002	−0.00	−0.01 to 0.00	0.359	−0.01	−0.02 to −0.00	0.010	−0.01	−0.02 to −0.00	0.032	0.00	−0.01 to 0.01	0.959
Random effects															
σ^2		0.73			0.50			0.63			0.58			0.57	
τ_{00}		$0.02_{County.FIPS}$			$0.01_{County.FIPS}$			$0.01_{County.FIPS}$			$0.01_{County.FIPS}$			$0.01_{County.FIPS}$	
		0.00_{week}			0.00_{week}			0.00_{week}			0.00_{week}			0.00_{week}	
ICC		0.03			0.02			0.02			0.02			0.01	
N		$554_{County.FIPS}$			$554_{County.FIPS}$			$554_{County.FIPS}$			$554_{County.FIPS}$			$554_{County.FIPS}$	
		31_{week}			31_{week}			31_{week}			31_{week}			31_{week}	
Observations		431,582			431,582			431,582			431,582			431,582	
Marginal R^2/conditional R^2		0.064/0.097			0.071/0.091			0.077/0.093			0.087/0.109			0.062/0.076	

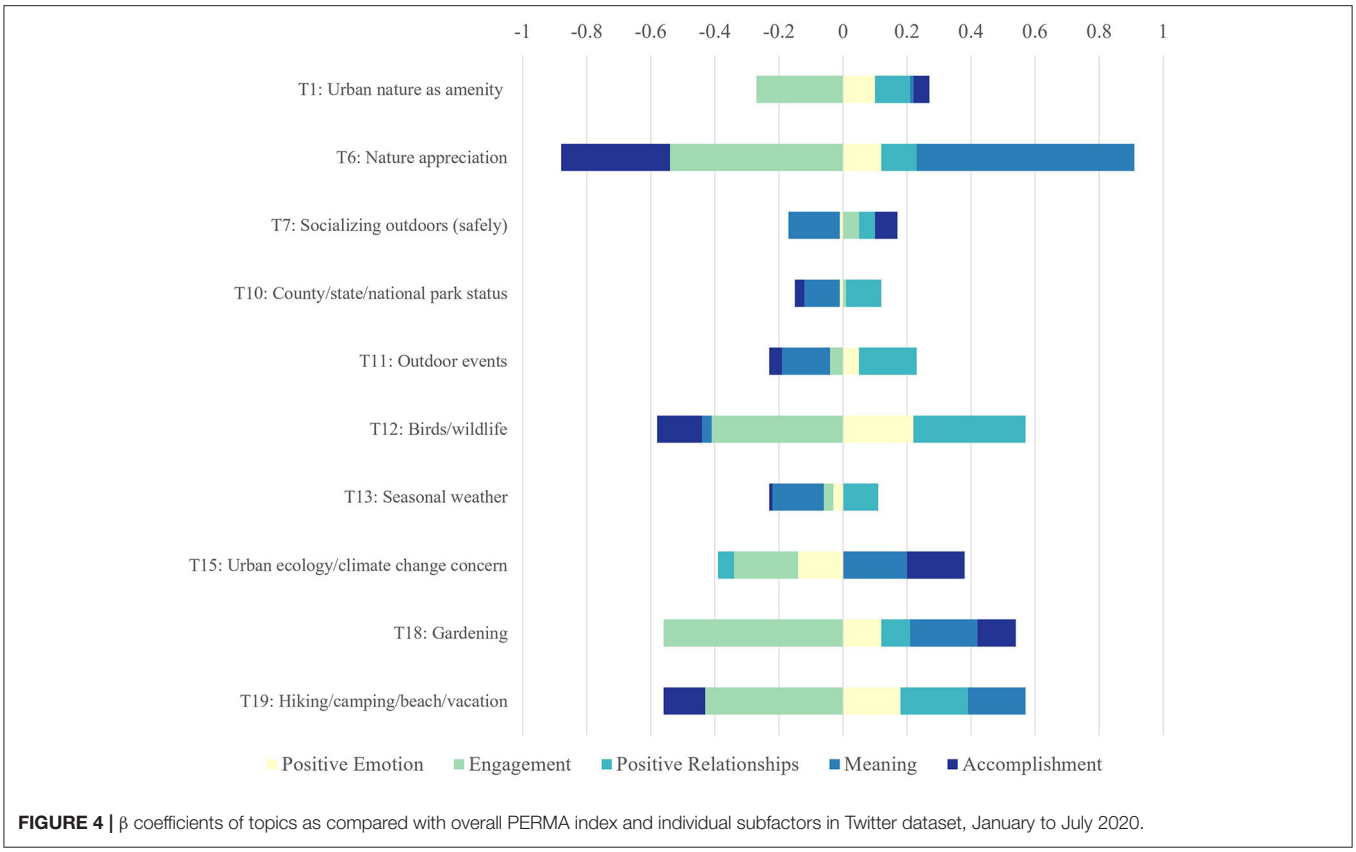

FIGURE 4 | β coefficients of topics as compared with overall PERMA index and individual subfactors in Twitter dataset, January to July 2020.

to benefit wellbeing during the pandemic. In particular, we find a positive relationship between nature connection and wellbeing during a stressful, collective disturbance, and the ongoing COVID-19 pandemic, per two pathways identified by Cleary et al. (2017): nature appreciation fostering intrinsic value and non-human relationships. These relationships suggest Tidball's (2012) concept of urgent biophilia may be at work during the pandemic, as a way to cope with this large-scale, ongoing disturbance. Our findings also support recent literature (Morse et al., 2020; Ugolini et al., 2020) showing that wellbeing is affected by the COVID-19 pandemic, by empirically demonstrating how subjective wellbeing changed between 2019 and 2020. Because the COVID-19 pandemic offers a natural experiment, our work answers Hartig's et al. (2014) call for population-level experimental studies on health–nature relationships, demonstrating specific aspects of nature that are beneficial to wellbeing, in particular to subfactors of the PERMA wellbeing construct. Our results also highlight the need for maintaining and expanding access to urban greenspaces in the future, for the benefit of all city residents.

Nature-Based Topics

Our study synthesized observational data from tweets to find that nature matters during the pandemic, with changes in activities discussed by Twitter users occurring beyond expected seasonal shifts. Topics around nature/greenspace in US-based social media during the pandemic focused on greenspace conditions, activities, nature experiences, values, and concerns. We observed topic prevalence to change year to year and across months; the *nature appreciation* and *birds/wildlife* topics seem to be the clearest depiction of people's increasing engagement with nature as a consequence of the pandemic. Activities described in tweets align with nature-based activities identified through surveys during the COVID-19 pandemic, including *Gardening* and *Hiking/camping/beach/vacation* (Morse et al., 2020; Ugolini et al., 2020). Rice et al. (2020) noted a decrease in camping and backpacking and an increase in hiking during the early months of the pandemic in the United States, but the coarseness of our topics does not enable us to separate hiking from the other activities in that topic.

Wellbeing and Nature-Based Topic Relationships

Our work provides further support for positive relationships between wellbeing and amount of greenspace in a county, but also goes further to examine how nature-based topics relate to wellbeing. Our mixed-effects models of county-level wellbeing from social media data support previous survey-based work that focused on city parks (Larson et al., 2016) and extend this work to all publicly available greenspace. Our work also examines which nature-based topics have larger relative effect sizes to other topics, comparable by β coefficients from our mixed-effects models. These effect sizes suggest the presence of multiple pathways for nature and greenspace to benefit wellbeing during the pandemic: providing opportunities to

socialize, strengthening nature connections through fostering intrinsic values and increasing non-human relationships, and providing activities such as gardening and hiking that can improve wellbeing through physical, mental, and emotional aspects. Below, we discuss the results of each nature-based topic in relation to wellbeing, aside from the *Seasonal weather* topic, which accounts for variation in weather year to year.

Socializing outdoors (safely) had a strong effect size in both 2019 and 2020, showing the enduring use of urban greenspaces for socializing. Strong social relationships are a known predictor of wellbeing (Kawachi and Berkman, 2001), and the act of socializing itself can reduce social isolation, a known predictor of poor health (Steptoe et al., 2013) that has deleterious effects on wellbeing during the pandemic (Clair et al., 2021). *Outdoor events* also had a strong effect size in both years, but with little variation between the 2 years in effect size. *County/state/national park status* was negatively correlated with wellbeing in 2019, but positively correlated with wellbeing in 2020, showing that discussion around park closings and openings relates to wellbeing differently during the pandemic.

Nature appreciation, the beginnings of nature connectedness, can foster intrinsic values (Weinstein et al., 2009), which in turn can lead to increased wellbeing (Ryan and Deci, 2000). Here, we find support for *Nature appreciation*'s positive association with wellbeing during the COVID-19 pandemic, with an increased effect size in 2020 as compared with 2019 and the second highest effect size of the nature-themed topics. Running a topic model on our tweet dataset does not enable us to examine the intricacies of these constructs' relationships, but the natural experiment of comparing before and during the pandemic offers strong support for this role of *Nature appreciation* in improving wellbeing during the pandemic across many cities in the United States. Further work could examine Tidball's urgent biophilia in relation to these constructs of nature appreciation, nature connectedness, intrinsic values, and wellbeing with methods that allow for stronger controls and within individual analyses, vs. our county-level analyses.

Birds/wildlife is a nature topic that is often viewed positively by the public. Bird-watching was observed in the media to increase during the pandemic, yet also was more likely to occur locally during the pandemic (Randler et al., 2020). Observing birds and wildlife offers the potential for non-human relationships to increase, another possible mechanism whereby nature connection affects wellbeing (Cleary et al., 2017). Non-human relationships also align with an increasing body of research on relational care (Jax et al., 2018) and biocultural stewardship (McMillen et al., 2020). Our mixed-effects models provide strong support for the role of non-human relationships in wellbeing. Lumber et al. (2017) five pathways for improving nature connectedness (contact, emotion, meaning, compassion, and beauty) align with positive emotion and meaning aspects of PERMA, and our subfactor models find support for positive emotion and meaning as they relate to both *Nature appreciation* and *Birds/wildlife*, among other nature-related topics.

Activities in greenspace also play a role in wellbeing. Here, our work identifies empirical differences in *Gardening* and *Hiking/camping/beach/vacation* as ways of experiencing nature; to date, much work has focused on each of these activities separately. We observe gardening and hiking/walking in parks are both positively associated with wellbeing. The nature of these activities varies, where gardening involves transforming and directly interacting with a place, and is a type of care, or stewardship (Enqvist et al., 2018), while hiking involves more passively experiencing a place, aligning with ideas of nature experiences as a dose (Kondo et al., 2020). Both it also includes physical activity, which is also known to be associated with wellbeing. Future work could further examine these specific activities in relation to wellbeing during disturbances in relationship to demographic factors.

Urban nature as amenity was another nature-themed topic that showed a positive relationship with wellbeing. Parks and other greenspaces are known to increase adjacent property values, highlighting the revealed preferences for nearby nature in cities (Conway et al., 2010). During the height of the pandemic in 2020, migration patterns highlighted that individuals were moving out of cities, perhaps temporarily, as nearby communities experienced increased property values (Coven et al., 2020; Gupta et al., in press). Within cities, access to greenspace, both public and private, has been a critical aspect of managing the pandemic, as evidenced by other nature-based topics' relationships with wellbeing. This nature-based topic and related relationship with wellbeing further highlight how urban nature has been viewed as an amenity by renters and homeowners. We also observed concerns about urban ecology conditions and climate change (*Urban ecology/climate change concern*), while negatively related to wellbeing, to decline during the early months of the pandemic. Aspects of PERMA affected here in particular include *Meaning* and *Accomplishment*. One possible explanation for this is that there is a finite pool of worry that an individual can draw from Weber (2006). However, survey-based research in the United Kingdom found no decrease in climate change concern during the pandemic (Evensen et al., 2021).

PERMA Subfactors and Nature-Based Topic Relationships

By examining wellbeing with a multidimensional construct, like PERMA, we are able to identify possible levers that could be used in therapeutic practice for enabling individuals to be resilient during stressful, ongoing collective disturbances. Previous work has examined resilience not only after individual events, but also in veterans (Pietrzak and Cook, 2013), where ongoing exposure to stressful events has resulted in PTSD and other mental health disorders. For many of the nature-based topics, positive emotions, meaning, and positive relationships were larger contributors to overall wellbeing than engagement and accomplishments during the 2020/COVID-19 time frame, suggesting these are the levers that may enable nature experiences to have a positive association with subjective wellbeing during the COVID-19 pandemic. Aspects of nature that have larger positive effect sizes with *Positive emotion*, *Positive relationships*, and *Meaning* include *Birds/wildlife*, *Socializing outdoors (safely)*, *Nature appreciation*, *Gardening*, and *Hiking/camping/beach/vacation*. During the

pandemic, our sense of accomplishment may be diminished, as many became housebound during "stay-at-home" orders, with Americans working from home for many, but not all job types. While attention restoration theory (Kaplan, 1995) identifies a positive relation between time in nature and attention, our dataset of tweets' engagement measures has small effect sizes. Because tweets are discussing nature rather than necessarily occurring while one is spending time in nature, it is possible the platform of social media could cause *Engagement* measures to be low. However, the effect size for *Socializing outdoors (safely)* in the *Engagement* mixed-effects model is equivalent to effect sizes for other PERMA subfactors, so it also could be that during the pandemic, time in nature may not be as absorbing. Levers that work for one individual, however, may not work for all. Here, we identify county-level, or community-level, relationships between conversations about aspects of nature and subjective wellbeing, but additional personal factors have the potential to meditate these relationships. Martínez-Martí et al. (2020) found character strengths to also play a role in wellbeing when monitoring individuals for one month during the COVID-19 pandemic.

Role of Stay-at-Home Orders

Our measures of county-level wellbeing demonstrate that wellbeing was lower in 2020 during the pandemic than at the same time the previous year. This supports ongoing weekly surveys measuring state-level anxiety and depression in the United States (Twenge and Joiner, 2020). Lockdown or "stay-at-home" orders are associated with decreased mental health (Le and Nguyen, 2021). By including the presence of stay-at-home orders in our models, we were also able to examine whether these orders affected wellbeing and, if so, through which pathways. We found negative associations between stay-at-home orders and wellbeing, but we speculate that the simultaneous positive relationships identified for nature may somewhat mitigate this effect. Other studies have shown access to nature during the pandemic has been uneven (Burnett et al., 2021; Jay et al., 2021), and our work further highlights the role that nature access can have on wellbeing.

Study Limitations

A few limitations apply to this research effort, many of which are inherent when working with social media datasets. Social media data can be biased, and because demographics data are not associated, this bias can be difficult to control for. We apply the PERMA-weighted lexicon, which has been validated in the literature against surveys, but in comparison to data-driven methods for measuring wellbeing in text datasets, associations with survey-based data are weaker (Jaidka et al., 2020). Survey-based methods with validated psychometric scales offer one of the best ways to measure wellbeing at present, yet they take time to implement and so are not as readily available as social media datasets. Surveys also offer the opportunity to identify differences in populations as to the role nature plays in coping during times of crisis (Morse et al., 2020). Social media datasets are also a measure of discussion about nature rather than self-reported measures or observed behavioral data. Yet, these types of data offer the opportunities for natural experiments during disturbances and can serve as a triangulation method, providing further support for or as an avenue for exploratory analyses that can identify new avenues for future work. Finally, we recognize that our comparisons between 2019 and 2020 also include variations between the years beyond the COVID-19 pandemic, so some variation we observe in wellbeing or nature-based topics between the years may not be attributable to impacts from the pandemic itself.

CONCLUSIONS

Urban nature plays a critical role in individuals' wellbeing, particularly as a coping mechanism for exposure to stressful events such as the COVID-19 pandemic. Our social media topic-based research makes use of a natural experiment, finding support for multiple pathways for nature to improve wellbeing during the ongoing pandemic, including socializing outdoors, nature appreciation, non-human relationships, nature-based activities, and access to nearby nature as an amenity. By applying a multidimensional construct such as PERMA, we are able to identify *Positive emotion*, *Positive relationships*, and *Meaning* as subfactors of wellbeing that can potentially be increased by urban nature. We find support for changes in motivation—the intrinsic interest of nature—from the prevalence of nature-based topics and wellbeing/nature-based topic relationships. Future work with social media datasets could examine an expanded time frame and sustained impact and across nations and cultures, as the COVID-19 pandemic continues to impact the global population. Survey and laboratory-based studies can further unpack the relationships we identify here between PERMA, nature connectedness, non-human relationships, relational care, and nature-based activities, to explore the multifaceted role of urgent biophilia in resilient responses to maintaining a sense of wellbeing during the COVID-19 pandemic. Our findings about urban nature and wellbeing suggest an opportunity to re-envision the distribution and access of greenspace within cities and broader metropolitan regions, to assist in supporting individuals' resilience during times of disturbance.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

MJ co-developed both the research question and study design and led the regression model development, spatial and analysis,

introduction, literature review, and discussion. SS co-developed the research question, study design, led the tweet data collection, topic modeling efforts, led the results section, and edited other parts of the manuscript. Both authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frsc.2022.725870/full#supplementary-material

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