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Original article

Automated photo content classification of Instagram posts to identify patterns of human uses in peri-urban protected areas: A case study from Vienna, Austria

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ABSTRACT

Blue and green spaces in cities provide essential ecosystem services to their inhabitants, including recreational and experiential opportunities. Their importance became further highlighted during the COVID-19 pandemic as urbanites sought to relieve some of the associated pressure. However, urban ecosystems are threatened by degradation and pollution, but also by other activities, including recreation. In this context, protected areas face the challenge of balancing visitor interests with conservation objectives, particularly in peri-urban areas. Social media provides an opportunity to analyse human activities in such areas. This study investigates spatial and temporal patterns in Instagram photos at three case study sites in Vienna, *Lainzer Tiergarten*, *Lobau,* and *Nussberg* with different protection statuses between 2018 and 2022. Automated content labeling using Google's Cloud Vision API and subsequent classification identified 19 clusters from 54,751 downloaded photos. Seasonal variations were observed, such as the prevalence of *Plant* and *Insect* photos in spring and summer, and *Landscape* content in autumn and winter. The COVID-19 pandemic coincided with and contributed to an increase in user activity, but seasonal trends were unaffected. Site-specific patterns also emerged, with *Panoramas* dominating in *Nussberg*, the *Riverscape* characterizing *Lobau*, and *Woodlands* dominating in *Lainzer Tiergarten*. Our findings demonstrate that automated social media photo content analysis can capture spatial and temporal variations in visitor behavior and landscape preferences, providing valuable insights for targeted visitor management and the establishment of conservation strategies in peri-urban ecosystems. Integrating these analyses with other methods, such as surveys or mobile phone tracking, can provide a more comprehensive understanding of human-environment interactions.

1. Introduction

Blue and green spaces are often described as the "pulsing veins" of cities, which provide essential services, habitats, and ecosystem functions in complex social-ecological systems (Adler and Tanner, 2013). They supply multiple fundamental ecosystem services (ES) to humans (Bolund and Hunhammar, 1999; Maes, 2016), including clean water, flood protection, air purification, and urban cooling (Gómez-Baggethun and Barton, 2013; Green et al., 2021; Lovell and Taylor, 2013; Elmqvist et al., 2015). Beyond these regulating and provisioning ES, urban and peri-urban blue and green spaces significantly contribute to mental and physical well-being by offering non-material services such as recreation,

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aesthetic experiences, and spiritual enrichment. These benefits, collectively referred to as cultural ecosystem services (CES) (La Rosa et al., 2016; MEA, 2005; Palliwoda and Priess, 2021), are increasingly recognized as essential to human well-being. Research highlights the growing reliance of people on CES (e.g. Chan et al., 2012; Gup et al., 2010; Plieninger et al., 2013). Furthermore, studies show that CES are valued on a similar level as regulating and provisioning ES (Martín-López et al., 2012) which underscores their significance to society. Despite their high importance to human well-being, many urban blue and green spaces are in poor condition (Maes et al., 2018; Kourdounouli and Jönsson, 2019) and face numerous threats, including degradation, fragmentation, pollution, and disruptions to nutrient and water cycles (Alberti, 2005). Such stressors are directly linked with a loss of ecosystem functions and, consequently, the provision of ES to people (Stanley et al., 2015; Rusche et al., 2019).

Besides these threats, human recreational activities pose additional significant challenges to ecosystems, negatively affecting plant and animal life cycles and disrupting habitats (Marion et al., 2016; Rusterholz et al., 2021; Schunko et al., 2021). Over the past decade, the recreational use of semi-natural and natural areas has increased (e.g., Pickering et al., 2018) and diversified (e.g., Koemle and Morawetz, 2016), further compromising ecosystem integrity. Associated impacts, such as littering, noise disturbance, habitat impairment, trampling of vegetation, soil compaction, and water pollution, have also intensified (Zingraff-Hamed et al., 2022; Kostrakiewicz-Gieralt et al., 2020; Marion et al., 2016; Rusterholz et al., 2021; Uzun et al., 2021).

This creates a conflict between the high importance and value of ES, particularly CES derived from experiencing nature, and the negative impacts of human use on the ecological integrity of urban and peri-urban blue and green spaces. This tension is heightened in protected areas, which are characterized by high ecological sensitivity and high attractiveness. While management plans for these protected areas often aim to mitigate stressors such as resource extraction, intensive land use, and pollution, they also regulate public access and often promote activities as leisure, recreation, and environmental education (Arnberger et al., 2021; Pickering et al., 2010). Although these activities provide significant benefits to humans, especially local populations, their activities inevitably harm protected habitats and species (Leung et al., 2018). Considering this conflict in the context of urban and peri-urban green and blue spaces, stressors related to visitation are even more pronounced due to their greater accessibility and higher visitation rates compared to more remote rural protected areas.

This tension between advantages and disadvantages of recreational use was further emphasized by the COVID-19 pandemic (Tansil et al., 2022). Lockdown restrictions, such as the closure of recreational facilities and social distancing, led to a significant increase in the public's reliance on green and blue infrastructure for leisure and exercise (Vimal, 2022; Todorova et al., 2023). This is because they provided a safe and accessible room for outdoor activities, in turn contributing to public well-being during a situation of stress (Labib et al., 2022). These pressures and conflicts highlighted the need for effective and adaptive visitor management strategies in urban and peri-urban blue and green spaces, especially those with protected status (Plieninger et al., 2015). This first requires comprehensive knowledge of recreational use patterns, such as spatial utilization and hotspot areas (Walden-Schreiner et al., 2018). Understanding of how people capitalize on their environment through different activities to fulfill recreational, spiritual, and/or aesthetic needs helps to untangle the complex interactions between human societies and natural ecosystems (Sinclair et al., 2019).

However, conventional visitor surveys and monitoring methods come with limitations and are associated with a high expenditure of time and financial resources (Schägner et al., 2017) and further show limitations regarding on site methods for example during COVID-19 pandemic. In this context, the ongoing digital revolution and the age of big data opens new opportunities to analyse human activities in space and time (e.g. Sessions et al., 2016; Wood et al., 2013; Keeler et al. 2015; Sonter et al. 2016). Especially data available from various social media channels promises novel insights into recreational uses to benefit conservation and management planning (Wood et al., 2013;). Therefore the analysis of social media data has been proposed as an alternative and complementary method to conventional monitoring approaches for recreational uses (Di Minin et al., 2015; Jarić et al., 2020). The continuous creation of data on social media platforms is one of the biggest strengths of this relatively new approach, enabling full timelines on the spatio-temporal trends of human use patterns in green and blue spaces, unlike the single-time steps gathered from field mapping (Toivonen et al., 2019). Still, there remain concerns with the quality of data and biases towards specific user demographics, as well as an overrepresentation of positive experiences (Ghermandi and Sinclair, 2019; Hausmann et al., 2020; Kaiser et al. 2021; Taczanowska et al., 2023; Toivonen et al., 2019).

When it comes to identifying human activities in recreational areas, social media platforms that focus on visual content, such as Instagram or Flickr, are prioritized in research (Di Minin et al., 2015; Tekanen et al., 2017). Comparing the amount of content and further the available data for analysis, Instagram emerges as the dominant platform (Tenkanen, et al., 2017), which can be explained through its steadily growing popularity and broad demographic reach (We Are Social, DataReportal, & Meltwater.,2024). In contrast, when examining trends in popularity, a recent study by Leppämäki et al. (2025) focusing on the platform Flickr revealed a significant decline in both the volume of data and user activity since its peak in 2011. Also, Instagram contains a high frequency of photos depicting people (Tekanen et al., 2017), personal moments and posts on leisure activity (Manikonda et al., 2021) compared to other platforms, which are often more dedicated to certain special interests. For instance, Flickr tends to feature a greater proportion of biodiversity-related photos (Tekanen et al., 2017), which could cater more towards other study interests for example focusing on biodiversity and environmental monitoring (Ghermandi and Sinclair, 2019) while information derived from Instagram provides a better basis for investigating human uses and preferences (Tenkanen et al., 2017). This constitutes an unprecedented and novel opportunity to observe behavior, narratives, and visions related to the environment and sustainability across cultures and over time, especially in urban and peri-urban environments, where its use is widespread (Ghermandi et al., 2023).

The Austrian capital Vienna and its 2 million inhabitants rely on an array of diverse green and blue spaces for local recreation and other human activities. Many of these areas are legally protected at various levels (e.g., Natura 2000 sites, national parks, biosphere reserves, and local conservation areas) and are well-connected to public transport, making them highly accessible. Especially during and after the COVID-19 pandemic, surveys on visitor-related challenges for nature conservation and area management were conducted (Tansil et al., 2022), however, primarily relying on qualitative interviews and less on robust quantitative data (e.g. Wipf et al., 2023).

Thus, the aim of this research is to demonstrate the usefulness of data obtained from social media for solving ecological problems related to the overexploitation of urban recreation areas under various nature conservation statuses using the city of Vienna as a case study. Using this novel approach, we specifically aim to clarify how unlocking the wealth of social media photos can be utilized to gain a better understanding of human use and perception of urban and peri-urban blue and green spaces with different protection statuses. In particular this is achieved by addressing the following three research objectives: First, we investigate which types of human uses and interests can be identified through a comprehensive clustering of social media photos taken in three study sites in Vienna. Second, we analyse differences in frequency and spatial distribution of human uses and interest between three specific case study sites of urban and peri-urban blue and green nature-protection areas. Third, we address how external factors - such as seasonality and the dynamics of the COVID-19 pandemic - affect the observed patterns within the areas and types of uses. Our results provide valuable insights into human-nature interactions, especially regarding the diverse interactions of people with peri-urban protected areas and the related ES they offer.

2. Material and methods

2.1. Study area

Three case-study areas with varying protection statuses were selected for the analyses within Vienna, Austria (Fig. 1). The main criteria for the deliberate selection of the three case study sites were their (i) importance as local recreation areas, (ii) protection status, and (iii) differences in environmental conditions. The three case studies are described to contextualize these criteria.

The first case study is the *Lainzer Tiergarten* in the southwestern part of Vienna, which covers an area of about 2250 ha of mainly forested land. It is designated under the EU's Habitats and Birds Directive (Council Directive 92/43/EEC; Directive 2009/147/EC) as a Natura 2000 EU protected area corresponding to IUCN Category IV (habitat or species management area; Lausche, 2011) and part of the *Wiener Wald* biosphere reserve. The main conservation assets include forest and meadow ecosystems and their associated species, such as the Ural owl *(Strix uralensis)*, fire salamander (*Salamandra salamandra)* or xylobiont beetles, e.g. the hermit beetle *(Osmoderma eremita)* or Rosalia longicorn *(Rosalia alpina)* (European Environment Agency, 2025). A stone wall surrounds the *Lainzer Tiergarten*, and thus, it can only be entered daily through open and closed gates. Opening hours are based on available daylight and a winter closure for most of the park. Further visitor regulations are in place, such as a ban on leaving trails, walking dogs, or cycling. To cater to visitors, several hiking trails lead through the area, meadows for resting and picnicking, forest playgrounds, historical monuments, educational opportunities, and a game reserve in additional fenced-off sections.

The second case study is the *Lobau* in the southeastern part of Vienna, which covers about 2300 ha of floodplain forest. It encompasses areas of Natura 2000 under the EU's Habitats and Birds Directive (Council Directive 92/43/EEC; Directive 2009/147/EC) and Ramsar Convention sites (https://rsis.ramsar.org) and forms part of the more extensive national park *Donau Auen,* extending beyond the city limits following along the Danube River. Besides various wetland habitats, steppe-type landscapes on deep gravel accumulations also have a precious nature conservation character, and the habitats are maintained accordingly. A high number of rare species find refuge there, including many amphibians, reptiles, birds and orchids, such as the Pannonian crested newt *(Triturus dobrogicus)*, the European Pond Turtle *(Emys orbicularis)*, the White-tailed eagle *(Haliaeetus albicilla)* and the burnt orchid *(Neotinea ustulata)* (European Environment Agency, 2025). As part of a national park, the management and maintenance concept conducted by the City of Vienna is tailored to individual habitats and various protected assets. Similar to *Lainzer Tiergarten*, visitor regulations such as staying on the paths apply. The area is frequently used as a recreation area, and the visitor pressure also conflicts with conservation goals (Arnberger et al., 2013).

The third case study is the Nussberg and Leopoldsberg complex, just *Nussberg* further on, and covers an area of about 1300 ha. It is located in the hilly northwestern part of Vienna and belongs to the Biosphere Reserve *Wiener Wald*, i.e., as a whole, it is not subject to as strong protection schemes as the other two areas. Only the forested steep northeast facing slopes are designated as Natura 2000 protected area under the EU Habitats Directive (Council Directive 92/43/EEC), along with two individual natural monuments according to IUCN Category III (Lausche, 2011). Due to its mosaic of vineyards, forests, orchards, dry stone walls, hedges and dry grasslands, the *Nussberg* represents the third type of investigated landscape in Vienna with high recreational value. The semi-natural features of the area provide habitats for rare species such as the Adriatic lizard orchid *(Himantoglossum adriaticum)*, the European green lizard *(Lacerta viridis)*, the Large copper *(Lycaena dispar)* and the wryneck *(Jynx torquilla)* (European Environment Agency, 2025). As part of the wine-growing region in Vienna, the area is known for its vineyards and wine taverns as well as the panoramic view of Vienna. Therefore, hiking, visiting wine taverns, and participating in sports activities are among the most popular leisure and recreational activities (Allex & Brandenburg, 2011).

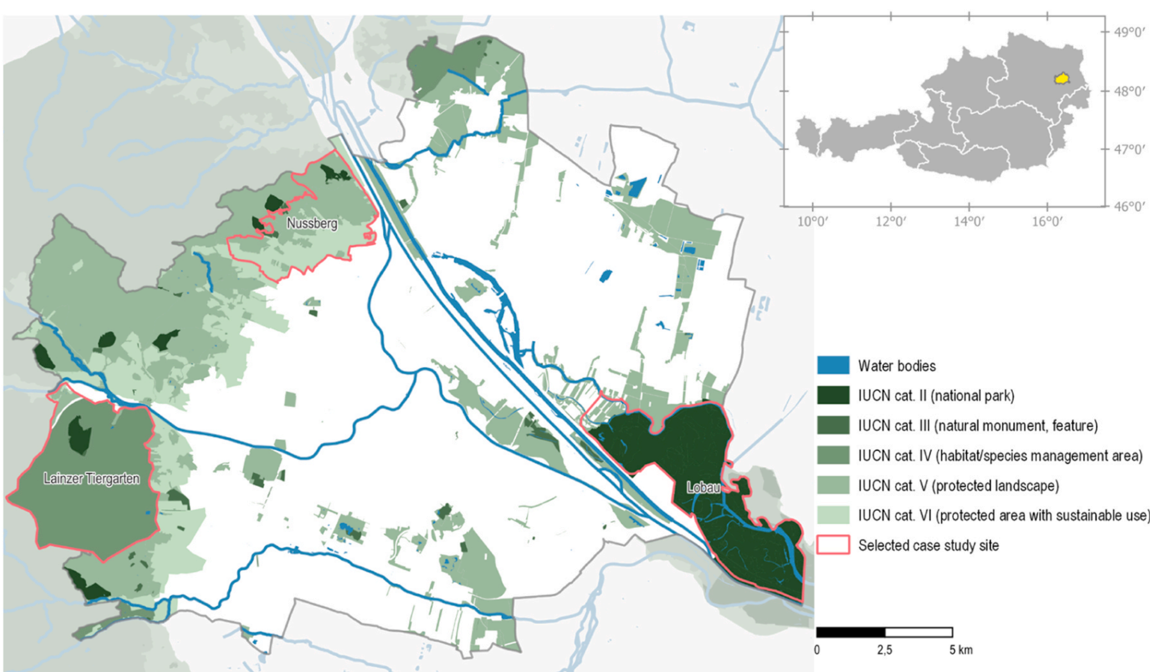

Fig. 1. City of Vienna with case-study areas delineated in red. Areas in shades of green indicate protected areas with differing protection status.

2.2. Selection of social media data

We collected photos posted on Instagram following Kaiser et al. (2021) to identify human recreational usage patterns in the three case study areas. The popularity and thus use of social media in general, and Instagram in particular, has been steadily increasing (Kemp, 2024; Chaffey, 2025). Therefore, we only focused on the years 2018–2022 to enable the analysis of monthly patterns. This, however, implies retrieving photos posted during the COVID-19 pandemic. During the pandemic, social media use has been affected by further spreading its popularity (e.g. Boursier et al., 2020; Chinna et al., 2021; Voss et al., 2023). As indicated by the data presented by Kemp (2021), there has been a 4.4 % increase in social media users in Austria between 2020 and 2021. Also, local recreational activities have changed, as lockdowns severely restricted them and spurred by travel bans to foreign countries (e.g. Gössling et al., 2020; Randler et al., 2020; Spence et al., 2020; Ugolini et al., 2020; Venter et al., 2020). Therefore, both the increase in the number of social media users as well as potential changes in user interests reflecting known changes in recreational patterns during the pandemic may pose possible biases in the data. To track these, we retrieved Instagram photos for two full years before and during the pandemic, i.e., between 2018-03–01 and 2022–03–01, allowing general conclusions while maintaining a data-rich source in addition to being able to identify responses in posted content to lockdown restrictions due to COVID-19.

Search terms, such as Instagram locations or hashtags, had to be identified first to source Instagram posts from the selected study areas. Users of Instagram are free to tag their posted photos with both locations as well as hashtags. Therefore, we rely on the correctness of their assignments and must assume that erroneous associations play no large part in the overall extensive number of postings to affect our analysis and conclusions. Manual verification that the posted photos stem from the areas of interest is impossible due to the amount of content. However, to our knowledge, there exist no other locations synonymous with which our three case study sites could be confused with. Hence, we decided to select the generic locations based on the names of the case study areas (i.e. *Lainzer Tiergarten, Lobau, and Nussberg and Leopoldsberg*) as well as their respective hashtags (#lainzertiergarten, #lobau, #nussberg, and #leopoldsberg). This ensured that both users who were familiar and unfamiliar with the Instagram location names were included in the dataset. More detailed locations exist within the respective study areas. However, while identifying appropriate locations, we detected a substantial decrease in the number of posts with a higher specification of locations. Furthermore, the specificity of hashtags declined, increasing the risk of including posts from outside our area of interest. Also, the existence of Instagram locations follows no objective pattern and thus, the respective number of smaller, more detailed locations within our three case study sites may be a mere artifact of the social media platform that disproportionately affects the number of found content in each site. Nevertheless, this implies that we knowingly did not extract all content on Instagram relating to our areas of interest to ensure a high level of objectiveness and reproducibility. In addition, we have no information on the number and content of photos that visitors to our case study sites post, without tagging them to any location or hashtag.

We used the application 4 K Stogram to obtain the data for our research (https://www.4kstogram.com/). This open-source software allows the extraction of all publicly posted photos in a given time frame for a search term, which can be a location or hashtag. Duplicate posts with the exact location and hashtag were deleted, and data for the locations *Nussberg* and *Leopoldsberg* were merged. Each downloaded photo was accompanied by metadata, including the upload time, username, caption, location, and hashtags used.

2.3. Photo content processing

Following Kaiser et al. (2021), photos were subjected to computer vision analysis by Google's *Cloud Vision API* (https://cloud.google.com/vision). The service returns labels describing the contents of photos along with a corresponding measure of reliability, i.e. the likelihood of occurrence, which must be higher than 0.5. The 20 most likely labels were collected, i.e. fewer than 20 labels were assigned if not enough labels were considered by computer vision to occur likely. We accessed the application programming interface *Google Cloud Vision* using the R package *RoogleVision* (Teschner, 2019) and processed the entire dataset.

Labeling Instagram photo content enabled the clustering of photos into groups of shared motives with commonalities regarding user activity and interest (Kaiser et al., 2021). To do so, we considered labels' presence/absence instead of the continuous reliability measure, which describes the likelihood of occurrence of a label, not its importance to the overall photo motive. Therefore, labels' presence/absence was used to generate a similarity matrix based on Bray-Curtis dissimilarity (Legendre and De Cáceres, 2013) with the function *vegdist* in the R package *vegan* (version 2.6–2, Oksanen et al., 2022). The matrix was then clustered hierarchically based on Ward's distance with the function *hclust* in base R (Guénard, Legendre, 2022). The hierarchical clustering was visualized in a dendrogram, and its shape and the number of elements per branch informed about an appropriate number of clusters. These were then verified by identifying the 20 most frequently occurring labels per cluster: If even the most common labels in a candidate cluster occur only in a few of its elements, the respective cluster is probably too general and represents more than one common motif. In such a case, the number of clusters must be increased in an iterative process. Upon refining and settling on the final number of clusters that best differentiate the relevant different kinds of photo contents, some clusters were yet again generalized due to a lack of meaningful variation in content.

2.4. Site differences and temporal patterns

When evaluating users and, thus, visitor preferences, the total body of posted photos reveals the breadth of experiences. However, the overall number of photos may be partly driven by single users posting more than one photo at a time. Therefore, to address spatiotemporal patterns in the social media perception of peri-urban green and blue spaces - irrespective of the posting behavior of individual users - one needs to correct for the latter. Thus, when assessing the actual number of users present at each case study site, the number of users posting at least one photo for a given site and day, so-called user days (UD), is tallied rather than the number of photos.

The calculation of UDs is based on the time of upload included in the metadata supplied with the photos and serves as a proxy for the point in time the photos were taken, which is not available. We assume that erroneous upload times even out in this large dataset and argue that the uncertainty introduced by this necessary step is permissible, as we investigate long-term and seasonal trends rather than daily and diurnal variations in user behavior.

We expected outdoor recreation to vary according to season and respective activity (Jones and Scott, 2006; Sun et al., 2024; Roemmich and Johnson, 2014). Hence, we assessed monthly counts of UD for each photo content cluster in each of the three case study sites. To test if UDs were distributed overall differently across the case study sites and photo clusters, we conducted a Chi-squared test of independence. To further evaluate whether certain case study sites were over- or underrepresented within a specific photo content cluster, we used one-sample binomial proportion tests, comparing the observed proportion of photos from each site within a cluster to that case study site's overall proportion across all clusters. Resulting p-values were corrected for multiple comparisons using the Bonferroni correction for multiple comparisons. In addition to statistical significance, we also calculated the difference between the observed proportion of photos from each case study site within a cluster to that case study site's overall proportion across all clusters and focused on meaningful effects where a cluster was over- or underrepresented at a study site by at least 10 %pt.

During the COVID-19 period, lockdown restrictions to varying degrees were put in place that also affected recreational activities by imposing restrictions on personal movement and the availability of leisure facilities or cultural sites (e.g. swimming pools, theaters) (Randler et al., 2020; Spence et al., 2020; Venter et al., 2020). To test for different posting behavior between the period before and during the pandemic using the onset of local COVID-19-related restrictions as the cut-off date (March 16, 2020) these regulations were categorized on a four-point scale (high, medium, low, none) corresponding to their severity (see supplementary material; Table S1, for detailed information on categorization of COVID-19 restrictions). To account for these influences on recreational activity, annual cycles were compared for the period before and during the COVID-19 pandemic.

To support this differentiation, daily rates of UD were compared between the different lockdown restrictions in a global one-way analysis of variance (ANOVA) and pairwise Wilcoxon rank sum tests using Bonferroni adjustment to account for the multiple comparisons.

2.5. Ethical and legal considerations

The use of passively crowdsourced data from social media platforms to study human-nature interactions has become an increasingly popular method in environmental science (e.g. Arts et al., 2015; Di Minin et al., 2021; Ghermandi and Sinclair, 2019; Ladle et al., 2016). While platforms such as Instagram offer valuable data resources, their use requires careful consideration of data protection, copyright, and ethical concerns (e.g. Di Minin et al., 2021; Ghermandi and Sinclair, 2019; Ma and Furuya, 2024; Teles da Mota and Pickering, 2020). Research has highlighted the absence of international regulations and standardized ethical guidelines for processing such data (Arts et al., 2015; Golder et al., 2017). To address the challenges identified, a qualitative review of studies that used 4 K Stogram for data collection similar to our approach was conducted (e.g., Brouard et al., 2022; Kaiser et al., 2021; Lee et al., 2025; Melo, 2024; Rhee et al., 2021; Smith et al., 2021; Ünal and Akyol, 2021; Zahroh et al., 2024). Best practices for upholding a high standard of research ethics were incorporated into our research process, particularly in data acquisition and further processing. Therefore, only publicly accessible Instagram posts from non-private profiles were used. User identification and links to original posts were removed, and no original data were stored. Inspection of the images was conducted exclusively by researchers and was not disseminated externally, following the recommendations set forth by Di Minin et al. (2021) and Ghermandi et al. (2023). To address concerns regarding data privacy, including the upload to Google's Cloud Vision API, our methodological approach was discussed and approved by BOKU University's data protection officer and legal department, ensuring that the strategy was carefully aligned with institutional standards and existing data protection legislation.

In detail, it was confirmed that the methodological approach to the provisions of the research exemption stipulated within the Austrian legal framework, as delineated in Article 89 of the General Data Protection Regulation (GDPR) in conjunction with § 7 of the Austrian Datenschutzgesetz (DSG, data protection legislation). Regarding copyright, Instagram does not claim ownership of user-generated content. The use of publicly available data for non-commercial, academic research is considered ethically justifiable.

By anonymizing user data, excluding private accounts, and obtaining institutional approval, we ensured compliance with privacy laws and comprehensive ethical consideration. While the use of tools like 4 K Stogram and cloud-based APIs raises valid concerns, our non-commercial, academic use of publicly available data adheres to ethical research practices.

3. Results

3.1. Photo retrieval

In total, we downloaded 54,751 photos for *Lobau* (n = 23,352), *Lainzer Tiergarten* (n = 16,380) and *Nussberg* (n = 15,019), covering the period from 1st of March 2018–1 st of March 2022. The photos accounted for 24,810 user days (UDs), i.e. a user posted at least one photo on a given day, and, respectively, 24,821 UDs per site, as eleven users posted at least one photo on two sites on the same day. The photos were posted by 11,540 unique users, of which 68.3 % only posted on a single UD (mean no. of UD = 2.15, max. no. of UD =110). and 55.6 % of users only posted a single photo (mean no. of photos = 4.75, max. no. of photos = 861). Less than 0.3 % of users posted more than 100 photos.

3.2. Photo contents

From all available photos, we identified 19 distinct clusters of common photo motives (Fig. 2, Table 1, Table S2). These resulted from a generalization of 25 clusters based on a common height, cutting the dendrogram's tree. This generalization was conducted since some larger clusters (e.g. riverscape views) would have been broken up into an unmeaningful number of sub-clusters that did not vary in depicted contents relevant to the study questions (e.g. riverscape views during different times of the day). Of the final 19 clusters, eight (n = 12,537, 22.9 % of all photos) did not specifically address the peri-urban green or blue space (*Buildings*, *Food*, *Drinks*, *Maps and signs*, *Cars*, *Interior, Stone & rock*, *Built-up spaces*), albeit it frequently served as background (e.g. open-air pubs) or is the location of certain well-known sights (e.g. *Buildings*, *Built-up spaces*). Four clusters (n = 10,883, 19.9 %) addressed *People* (*People*, *People in nature*) or specific outdoor activities (*Bicycles*, *Dogs*). The remaining nine clusters (n = 31,331, 57.2 %) were either related to particular *Biological elements* in the natural environment (*Insects*, *Plant macro*, *Tetrapods Birds*) or environments at the *Landscape* level (*Woodland*, *Panorama*, *Riverscape*).

3.3. Spatio-temporal patterns

The distribution of the eleven photo content clusters that address peri-urban green and blue spaces across the three case study sites showed particular contents which are more associated with a specific site than others, as revealed by the Chi-squared test of independence, X^2 (36, N = 54,751) = 18,664, p < .001 (Fig. 3). In fact, of the eleven clusters depicting peri-urban green or blue space, all but one cluster were significantly over- and/or underrepresented for at least two case study sites as revealed by one-sample binomial proportion tests, comparing the observed proportion of photos from each site within a cluster to that case study site's overall proportion across all clusters (Table 1). Only the cluster *People* followed the overall distribution of all photos across the three sites (*Lobau* 42.65 %, *Lainzer Tiergarten* 29.92 %, *Nussberg* 27.43 %) without a statistically quantifiable deviation, with differences less than one percentage point.

For all other photo content clusters, the proportion of at least one site deviated by more than ten percentage points from the overall distribution of all photos across the three sites, revealing meaningful as well as statistically significant differences:

Photos of *People in nature* were underrepresented in the *Lobau* (-17.7 %pt.). However, photos of *Bicycles* (+34.57 %pt.) and *Dogs* (+30.17 %pt.) were both positively associated with the *Lobau,* as were three of the four *Biological elements* clusters (*Birds* +32.33 %pt., *Insects* +34.81 %pt., *Plant macros* +11.54 %pt.) The fourth *Biological elements* cluster *Tetrapods,* was positively associated with the *Lainzer Tiergarten* (+22.75 %pt.).

The three clusters in the Landscape category were each associated with one corresponding case study site, *Woodland* with the *Lainzer Tiergarten* (+16.46 %pt.), *Panorama* with the *Nussberg* (+31.18 %pt.),

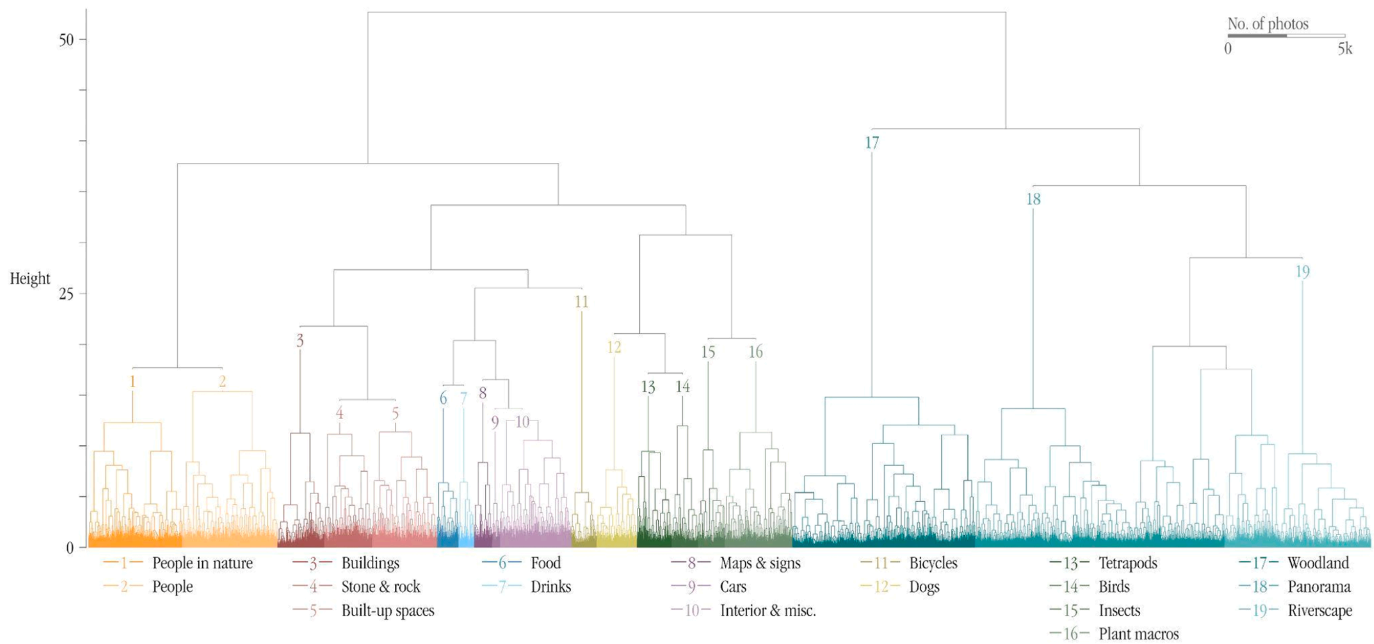

Fig. 2. Dendrogram of all 54,751 photos from the three study areas forming 19 distinct photo content clusters.

and *Riverscape* with the *Lobau* (+39.62 %pt.).

The rate of UDs varied over the study period with a marked effect of the COVID-19 pandemic (Fig. 4a). Rates of UDs increased from none to high severity of lockdown restrictions with corresponding statistically significant differences (pairwise Wilcoxon test) between all levels except for the comparison of medium to high degree of lockdown restriction (global one-way ANOVA, $F(3, 1457) = 125.3$, $p < 2e\text{-}16$; Fig. 2b).

The comparison between cluster-specific temporal patterns confirmed the generally higher number of UD during the COVID-19 pandemic (Fig. 2), yet the clusters' seasonal patterns were hardly altered by the imposed restrictions (Fig. 5). This means that photo content clusters peaking during a particular month before the pandemic also did so for the period when COVID-19-related restrictions were imposed. Hence, the overall trend for a summer depression in the number of UD persisted, and was exaggerated slightly for most photo content clusters during the pandemic. Only during three months, more photos were posted before the pandemic than during, albeit at very low levels for *Insects* in March, *Birds* and *Tetrapods* in August (Fig. 6). *Birds* seemingly were of much more focus in January during the pandemic, which could be an artifact due to the very low number of UD before the pandemic for January.

4. Discussion

The findings of our study illustrated the potential benefits and challenges of using automated social media photo content classification to investigate human usage patterns in peri-urban protected areas. Exploiting Instagram data from three different case study sites in Vienna – *Lainzer Tiergarten*, *Lobau*, and *Nussberg* – we gained insights into spatial and temporal patterns of recreational activities and landscape preferences. These findings have the potential to contribute to both theoretical and practical developments in ecosystem management, as well as to the integration of novel data sources into conservation planning.

4.1. Human uses and impacts

Across the investigated locations, we identified different human uses within peri-urban green and blue spaces. For example, areas with scenic or tourist locations in the *Nussberg* area (view at the Danube) or *Lainzer Tiergarten* ("Hermesvilla" - historic building) acted as "pull factors" for visitors. Such insights could guide visitor management, e.g. in nearby areas exposed to trampling, littering or illegal activities such as collecting protected plants (Šmelhausová et al., 2022). Further, understanding how different photo contents correlate with CES such as physical activities, social interactions or esthetic appreciation through such analyses provides new insights into human-nature interactions (Kaiser et al., 2021).

Our findings aim to clarify how social media posts contribute to a better understanding of human use in peri-urban recreational areas with varying protection statuses. By analysing user-generated content, we identified patterns of visitation and activities, offering valuable insights for effective management and conservation strategies. For instance, studies have demonstrated that geotagged photos from platforms such as Flickr can serve as indicators of recreational use in urban and peri-urban forests, aiding in the assessment of CES (Wartmann et al., 2021). Additionally, social media data research has highlighted the potential to monitor human activities and their impacts within protected areas, informing targeted conservation efforts (Levin et al., 2017). In Vienna, analysing social media photos taken in recreational and conservation areas revealed specific human uses and pressures, facilitating the development of tailored management plans that balance public enjoyment with ecological preservation.

4.2. Spatial and temporal patterns

Our results showed clear differences between photo clusters between the three investigated locations. Panorama views were widespread in the hilly *Nussberg* area, whereas photos of water and the floodplain were more common in the *Lobau* area, and woodland photos were mainly associated with the *Lainzer Tiergarten*. This pattern suggests that the users frequenting these sites are attracted by their distinct natural characteristics which is reflected in the type of photos they post online. These findings underline the validity of social media photo content analysis as a tool for detecting user preferences and site specific characteristics, even in areas where a priori expectations are limited.

The *Lobau,* as part of the national park *Donau-Auen,* enjoys the highest protection status of the three study sites. This corresponds with our finding that most photos were posted in the *Lobau.* Further, all clusters related to nature observation, expect *Tetrapods*, which were mainly posted in *Lainzer Tiergarten,* being disproportionately

Table 1

The 19 photo content clusters distributed across the three case study sites (Lainzer Tiergarten, Lobau, Nussberg). Clusters related to peri-urban green and blue spaces are grouped into three categories: *Outdoor Recreation*, *Biological Elements*, and *Landscape*. For each cluster, the total number of photos and the number per site are shown. From these, the proportion of each site within a cluster is calculated (*prop. site in cluster(%)*) and compared to its overall share across all clusters (*Δ prop. (cluster - site overall (%pt.)*). Differences > 10 %pt are shown in bold. Statistically significant over- or underrepresentation is marked with plus/minus signs based on Bonferroni-adjusted p-values ($p \leq 0.05$: ±, $p \leq 0.01$: ±±, $p \leq 0.001$: ±±±).

Cluster			Lainzer Tiergarten				Lobau				Nussberg			
Category	Name	n photos	n photos	prop. (%) site in cluster	Δ prop. (%pt.) (cluster - site overall)		n photos	prop. (%) site in cluster	Δ prop. (%pt.) (cluster - site overall)		n photos	prop. (%) site in cluster	Δ prop. (%pt.) (cluster - site overall)	
	Buildings	1999	1663	83.19			97	4.85			239	11.96		
	Stone & rock	2047	761	37.18			794	38.79			492	24.04		
	Built-up spaces	2772	1093	39.43			831	29.98			848	30.59		
	Food	922	289	31.34			282	30.59			351	38.07		
	Drinks	661	46	6.96			62	9.38			553	83.66		
	Maps & signs	770	206	26.75			457	59.35			107	13.90		
	Cars	330	11	3.33			257	77.88			62	18.79		
	Interior & misc.	3036	1052	34.65			1485	48.91			499	16.44		
Outdoor recreation	People in nature	3998	1565	39.14	9.23	+ ++	996	24.91	−17.74	—	1437	35.94	8.51	+ ++
	People	4070	1250	30.71	0.80		1734	42.60	−0.05		1086	26.68	−0.75	
	Bicycles	1093	86	7.87	−22.05	—	844	77.22	34.57	+ ++	163	14.91	−12.52	—
	Dogs	1722	104	6.04	−23.88	—	1254	72.82	30.17	+ ++	364	21.14	−6.29	—
Biological elements	Tetrapods	1483	781	52.66	22.75	+ ++	632	42.62	−0.03		70	4.72	−22.71	—
	Birds	1107	242	21.86	−8.06	—	830	74.98	32.33	+ ++	35	3.16	−24.27	—
	Insects	1158	216	18.65	−11.26	—	897	77.46	34.81	+ ++	45	3.89	−23.55	—
	Plant macros	2892	819	28.32	−1.60		1567	54.18	11.53	+ ++	506	17.50	−9.93	—
Landscape	Woodland	7793	3614	46.37	16.46	+ ++	2940	37.73	−4.93	—	1239	15.90	−11.53	—
	Panorama	10,654	2154	20.22	−9.70	—	2256	21.18	−21.48	—	6244	58.61	31.18	+ ++
	Riverscape	6244	428	6.85	−23.06	—	5137	82.27	39.62	+ ++	679	10.87	−16.56	—
	Total	54,751	16,38	29.92			23,352	42.65			15,019	27.43		

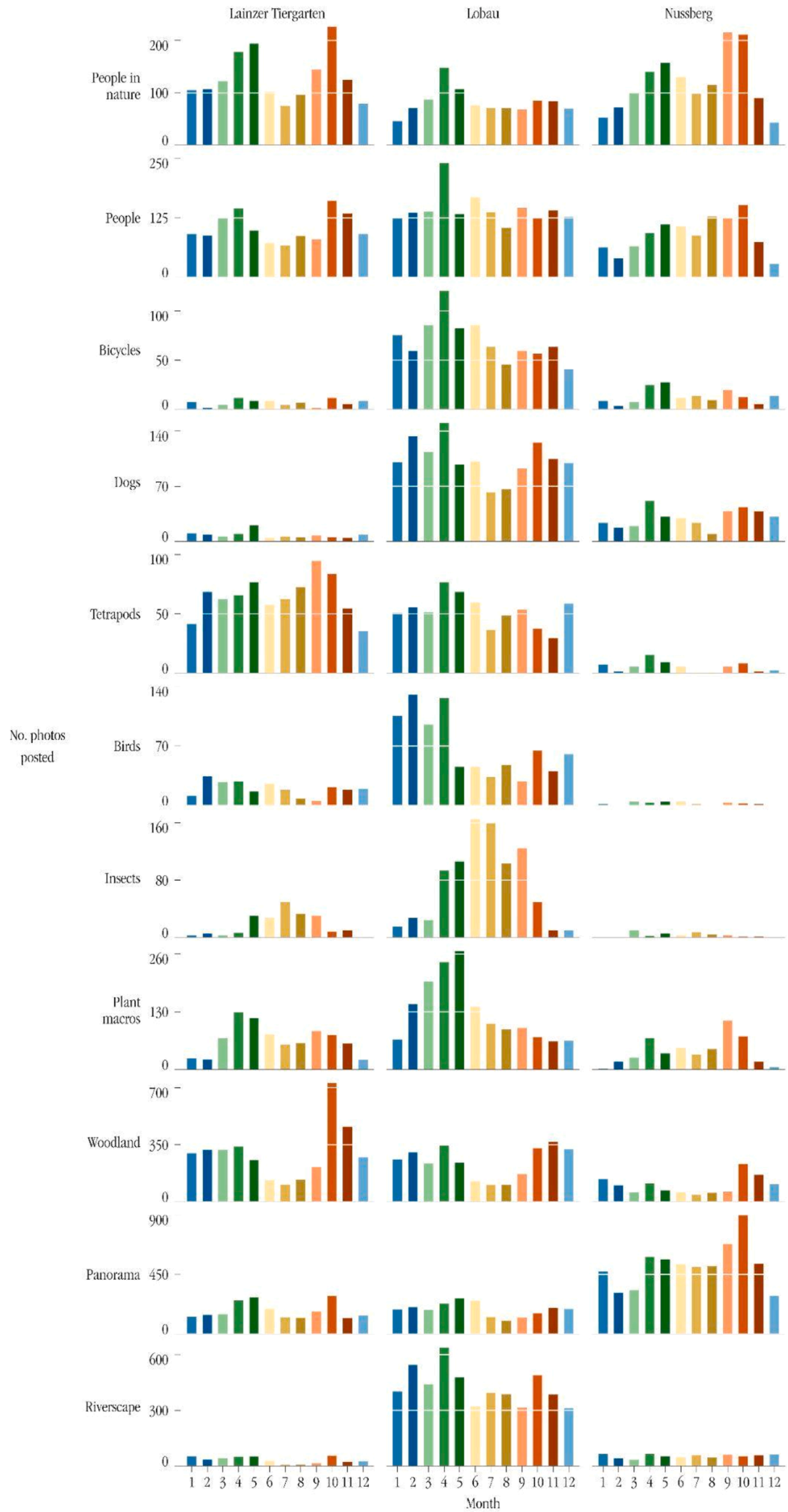

Fig. 3. Distribution of photos in content clusters addressing peri-urban green and blue spaces across the three study sites and months of the year (1–12). The Y-axis is adjusted for the total cluster size for each row. Colouration represents months of the year and season (blues = winter; greens = spring; yellow = summer; red = autumn).

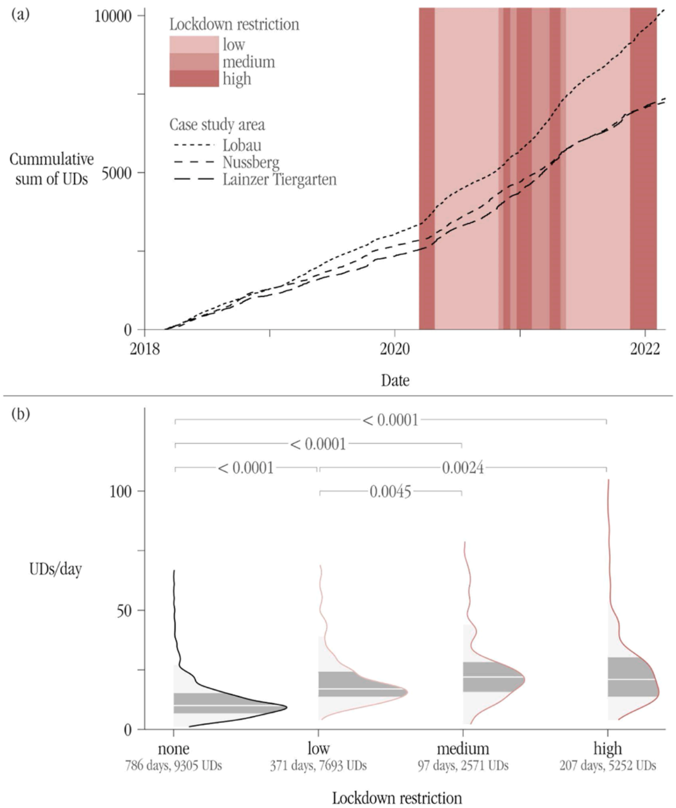

Fig. 4. (a) Cumulative sum of user days (UDs) at the three case study sites. The uptick in frequency after the outbreak of the COVID-19 pandemic was accompanied by the severity of corresponding countermeasures (Lockdown restrictions). (b) Half-violin plots with a boxplot-like colouration of quantiles are used to compare rates of UDs for days with at least one UD, for the different severity of lockdown restrictions. Significant differences are noted with the corresponding comparisons' p-value from a pairwise Wilcoxon rank sum test with Bonferroni adjustment for multiple comparisons.

overrepresented in the *Lobau* Additionally, the *Lobau* also forms a distinct cluster of *Riverscape* photos, the most specific *Landscape* cluster over the more general *Woodland* and generic *Panorama* photos. This can be interpreted as evidence that social media content responds to an area's ecological appearance and integrity reflecting the impact of high protection and conservation efforts.

From an applied perspective, the fact that visiting users perceive this heterogeneity in natural site conditions (hilly, woodland and floodplain) suggests that visitor management strategies should be tailored to specific site characteristics and stressors, as Mateos et al. (2020) also highlighted. Natural features that strongly attract visitor attention, such as scenic trees or flowering meadows, should be integrated into conservation plans to minimize the impact (Rusterholz et al., 2021). Our analysis also revealed seasonal variations in user activity and photo content such as a higher prevalence of plant and insect photos (nature observation) during spring and summer and a higher number of landscape features in autumn and winter, e.g. floodplains more visible when trees are bare (Litleskare and Calogiuri, 2022). These seasonal dynamics align with previous findings (e.g. Junge et al., 2015; Sessions et al., 2016; Walden-Schreiner et al., 2018) that document shifts in aesthetic and ecological visibility influencing visitation patterns. Langemeyer et al. (2018) have also emphasized the importance of incorporating seasonal preferences in future landscape perception studies.

These insights highlight how seasonal aesthetics and ecosystem visibility may affect when and why people visit specific areas, which could inform the timing of conservation and management actions. Further, detecting visitation patterns in peak seasons can help improve targeted visitor guidance to either disperse or concentrate use appropriately (Marion et al., 2016). Public education efforts must also be strategically timed and located to increase awareness and encourage responsible behavior (Uzun et al., 2022). Adapting management strategies to identify spatial and temporal patterns can help mitigate environmental pressures while enhancing visitor experiences. Our approach presents a readily available tool to quickly estimate temporal visitor dynamics by measuring user and posting frequencies as a proxy.

The increased social media activity observed across the three case study sites during the COVID-19 pandemic, along with the interpretation of rising visitation, is strongly supported by the findings of Wipf et al. (2023). Their study is among the few that compare pre- and post COVID recreation patterns including on site data collected from visitor surveys, also prior to the pandemic. Their research experienced a significant surge of 55 % in visitor numbers in 2020 compared to previous years, primarily driven by domestic visitors who would have otherwise traveled abroad. This underscores the critical role of protected areas as recreational refuges during times of crisis and reinforces the importance of peri-urban green and blue spaces as essential recreational infrastructure. These findings align with the growing recognition of such spaces as vital resources for public well-being, particularly during global disruptions (Ciesielski et al., 2024; Samuelsson et al., 2020; Venter et al., 2020). Hence, this study highlights the potential of social media data in detecting shifts in use patterns caused by external factors, such as lockdowns and travel restrictions, as well as the growing importance of such spaces for local recreation.

4.3. Uncertainties and limitations

Awareness of the limitations and challenges of using social-media data, e.g. sourced from Instagram, is necessary when evaluating the presented approach for other applications.

First, almost two-thirds of Instagram users are under 35 years old (Taczanowska et al., 2024). This may introduce biases that only partially represent some visitor groups, such as the elderly or younger children. However, Instagram is still the most inclusive social media platform (We Are Social, DataReportal, & Meltwater.,2024). Moreover, other methods, such as questionnaires or workshops, come with their own biases, including sampling bias, non-response bias, and response bias, which can compromise the accuracy of the collected data (West and Blom, 2017).

Second, another commonly overlooked aspect when interpreting the results of social-media analysis are temporal dynamics intrinsic to social media use. On the one hand, posted content on Instagram may disappear over time which is presumably due to changed privacy settings or deleted posts or deleted accounts. This poses a significant challenge for long-term quantitative analyses, as there is no evidence on how older posts may be disproportionately affected by content loss over time. On the other hand, as Instagram grows in popularity, long-term quantitative trends over time may not only be driven by changes in visitors' interest or behavior but also by the sheer number of active users. This is difficult to account for and must be considered. Nevertheless, in our study, the observed increase in Instagram posts from our case study sites and the reported number of users (Kemp, 2021; Voss et al., 2023) are probably both joint effects of the pandemic and are therefore being interpreted in conjunction with each other. Effectively, the more widespread use of Instagram and the thus increased number of users are necessary to detect the increased number of visitors and visits to the peri-urban case study sites of blue and green infrastructure.

Third, a more apparent limitation of Instagram are deficits in georeferenced data, which necessitates relying on the accuracy of Instagram locations and hashtags. In this study, due to the general nature of the location names used and a visual inspection carried out, we assume that, at worst, a few number of photos that do not stem from these locations were included in the analysis.

Fourth, Instagram is also a platform for influencers and commercial

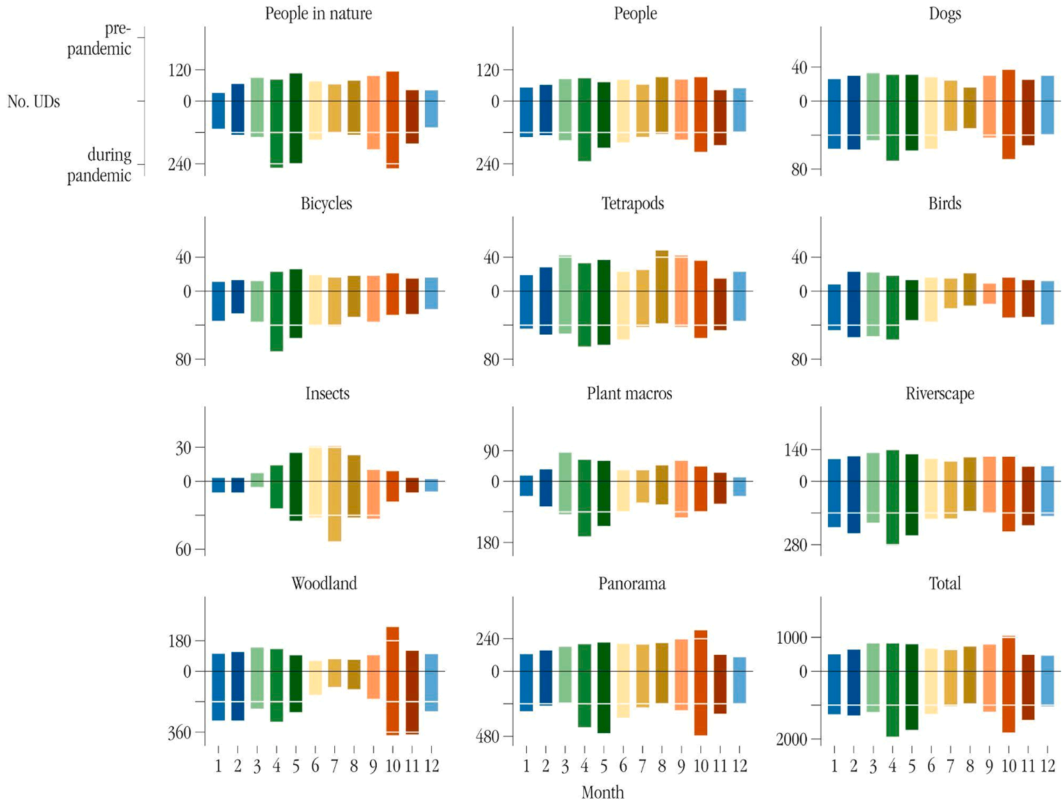

Fig. 5. Monthly (1 = January to 12 = December) distribution of user days (UD) across the photo content clusters addressing peri-urban green and blue spaces pooled for the three study sites. UDs from before the COVID-19 pandemic are shown in the positive direction and from during the pandemic in a negative direction (cut off date is the onset of COVID-related restrictions on March 16, 2020). The Y-axis is adjusted for the total cluster size for each histogram. Colouration represents months of the year and season (blues = winter; greens = spring; yellow = summer; red = autumn).

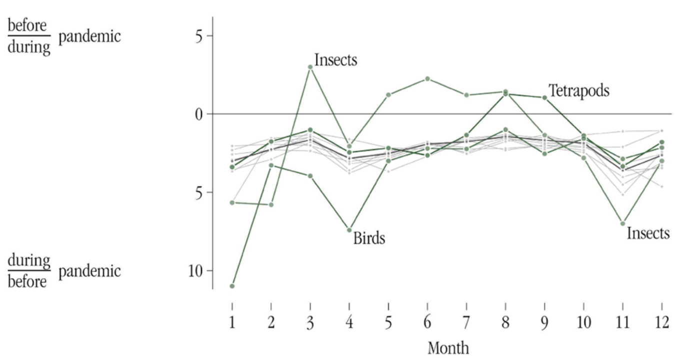

Fig. 6. Monthly (1–12) ratio between the number of user days (UD) for the two periods, before and after the onset of COVID-related restrictions on March 16, 2020, for each cluster. If the number of monthly UDs was higher before the pandemic's beginning, the ratio before/during the pandemic is given (positive direction on the axis). In contrast, if the number of monthly UDs was higher during the pandemic, the ratio during/before the pandemic is given (negative direction on the y-axis). The thick, dark line is the total number of UD, pooled across all photo content clusters. Photo content clusters, *Birds*, *Insects,* and *Tetrapods* are colored in shades of green due to their divergence from the overall pattern.

interests. This is a factor when considering frequencies of posts by certain user accounts and a large number of UDs or photos could be indicative of a corporate/professional account. In this study, we deemed the number of 0.3 % percent of all users behind our data that posted more than 100 photos to be permissible, but this may vary due to research interests.

Furthermore, while photo content offers valuable qualitative and quantitative insights, it alone is an incomplete indicator for users' interests and their valuation of peri-urban green and blue spaces. This limitation is especially true for CES assessment. Even though automated photo content classification is shown to be capable to differentiate decapitated photo motives, the interpretation regarding CES remains complex. For instance, photos of *Bicycles* could easily be linked to physical exercise, i.e. a recreational value. However, photos of dismounted bicycles placed in front of a scenic background also imply that the respective riders also were aware of the experiential value of their surroundings. So far, automated approaches offer no universal solution to reliably linking depicted motives to CES across all its classes of values (Alieva et al., 2022). Especially, the analysis of accompanying photo captions might warrant more insights in this regard by taking into account the intentions of users posting (Kaiser et al., 2021). For example, they give necessary context information or reveal tonal characteristics of the post, such as sarcasm, which would not be apparent from the photo depiction. Further research hence should explore ways to integrate photo content analysis with content from other social media platforms, text postings, shared or favored content, and demographic data to address current preconceptions as Tenkanen et al. (2017) suggest. Comparative studies between automated and manual content analysis methods, as Wood et al. (2013) suggested, could refine the reliability of such approaches (Canhoto and Padmanabhan, 2015). It would also be beneficial to consider integrating such approaches with complementary methods, for example, citizen science or mobile phone tracking, to gain a more holistic view of human-environment interactions (Tenkanen et al., 2017).

4.4. Future directions

Our study demonstrates the potential of using social media data as a supplementary approach to common methods for guiding peri-urban ecosystem management. Despite the identified limitations, automated photo content classification provides a novel perspective on human-nature interactions, enabling the identification of critical use patterns for the sustainable management and conservation of peri-urban green and blue spaces. By addressing challenges and integrating multiple data sources, this approach can inform efforts to foster and preserve the resilience of urban ecosystems in the anthropocene (Yang and Liu, 2022). While automated photo content analysis offers valuable insights, interpretations based solely on this method should be approached cautiously, as they may overlook site specific contents missing on social media. Combining automated techniques with human classification and other data sources - such as mobile phone tracking, citizen science applications, visitor surveys, or ecological monitoring - can enhance accuracy and provide a more comprehensive understanding of human-nature interactions. Social media data research has highlighted the potential to monitor human activities and their impacts within protected areas, informing targeted conservation efforts (Levin et al., 2017). Also, it has served to study human preferences and CES provided by the environment further operationalizing it from a management perspective (Svobodova et al., 2025). Thus corresponding approaches can support adaptive management strategies that respond dynamically to changing recreational patterns and environmental pressures, ultimately contributing to more resilient peri-urban green and blue spaces in the face of ongoing social and ecological transformations.

5. Conclusions

This study highlights the potential of social media data, specifically Instagram photo content, as a valuable tool for identifying human-nature interactions in peri-urban protected areas. By analysing spatial and temporal patterns across three case study sites in Vienna — *Lainzer Tiergarten, Lobau, and Nussberg* — we identified distinct recreational activities and landscape perceptions influenced by site-specific characteristics, seasonal variations, and external factors such as the COVID-19 pandemic. Our findings underscore the importance of tailoring visitor management strategies to the unique ecological and recreational attributes of each site to balance conservation goals with recreational use.

While automated photo content analysis offers novel insights, integrating this approach with complementary methods, such as visitor surveys and ecological monitoring can provide a more comprehensive understanding of human impacts on peri-urban green and blue spaces. This integration is crucial for developing adaptive management strategies that enhance the resilience of peri-urban ecosystems within ongoing social and ecological transformations. Future research should explore the potential of combining social media data with other datasets to refine methodologies and address current limitations, ensuring robust and actionable outcomes for peri-urban ecosystem management.

CRediT authorship contribution statement

Martin Palt: Writing – review & editing, Writing – original draft, Visualization, Supervision, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Michael Binder:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Anna Huber:** Writing – review & editing, Writing – original draft, Project administration, Formal analysis, Data curation. **Christa Hainz-Renetzeder:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Alice Wanner:** Writing – review & editing, Funding acquisition. **Lena Ortega Menjivar:** Writing – review & editing, Writing – original draft, Formal analysis, Data curation. **Nur Banu Özcelik:** Formal analysis, Data curation. **Friedrich Leisch:** Formal analysis, Data curation, Conceptualization. **Florian Borgwardt:** Writing – review & editing, Methodology. **Kaiser Nina:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Stefan Stoll:** Writing – review & editing. **Rafaela Schinegger:** Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization.

Declaration of Generative AI and AI-assisted technologies in the writing process

While preparing this work, the authors used Grammarly and DeepL to improve the English writing of specific phrases. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the publication's content.

Declaration of Competing Interest

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

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ufug.2025.129029.

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