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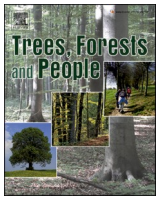

Adapting to change: Visitor patterns in national parks across the pandemic timeline

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ABSTRACT

The COVID-19 pandemic has substantially impacted visitor behaviour and forest tourism management, introducing new visitor patterns that persist in the post-COVID-19 period. As critical components of national parks, forests and tree-dominated natural environments have gained renewed attention for their role in promoting mental and physical health during public health crises. This study analysed pandemic-induced shifts in visitor activity and movement patterns from a temporal-spatial perspective in Banff, Jasper, Yoho and Kootenay National Parks using social media big data from pre, *peri*, and post COVID-19. Temporal analysis of social media posts aligned with official park attendance trends (2019–2023), validating big data as a reliable indicator. Results show a long-term behaviour shift toward nature-immersive activities in remote and forested wilderness areas, reduced traffics on historically popular routes, and emerging between-park connectivity. Seasonal and spatial visitation patterns became less centralised, increasing conservation pressures in ecologically sensitive forested areas and necessitating proactive infrastructure, zoning, and transit management. This research fills the knowledge gap on pandemic-driven visitation trends using big data, offering the implications extend beyond the current pandemic for effective and prompt park resources and tourism management, balancing conservation and public well-being.

1. Introduction

The COVID-19 pandemic has significantly impacted national park visitation and associated travel behaviour, which has posed unprecedented challenges to the tourism industry and management globally (Ferguson et al., 2023; Geng et al. 2024a). At the early stage of the pandemic, stay-at-home requirements, travel restrictions, closure of urban public spaces and other safety protocols were key measures to tackle the pandemic and reduce the spread of the virus (Honey-Roses et al., 2020). As a result, national parks across the world received significant tourism and revenue reductions (Spenceley et al., 2021; Geng et al., 2024b). As the pandemic unfolded, natural areas received renewed attention due to their crucial functions during health crises, such as providing safe spaces for healthy outdoor recreation and reducing the negative impacts of the pandemic and response restrictions on people's mental and physical health (Samuelsson et al., 2020; Rice and Pan, 2021; Geng et al., 2021). Previous research also confirmed the increasing demand for park experiences during and after the pandemic, as well as adapted travel behaviours and visitation patterns. For example, visitors tended to go to more remote areas instead of traditionally popular spots during their travel to national parks (Samuelsson et al., 2020; Geng et al., 2024b). Additionally, there was a significant increase in camping activities following the onset of COVID-19, as reported in the Annual North American Camping Report (Cairn Consulting Group, 2022). Therefore, much progress and effort need to be made in national parks to achieve sustainable tourism management in the context of the post-pandemic transformations.

Regarding COVID-19 and future potential health crises, monitoring and managing visitor activities and movement in national parks is crucial for effective tourism management, product development and marketing, public transportation management, and reducing crowding and conflicts in order to meet both recreation and conservation

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objectives (Manning and Valliere, 2001; Lew and Mckercher, 2006; Mckercher and Lau, 2008; Orellana et al., 2012; Hu et al., 2019; Huang, 2023). However, the COVID-19 pandemic has changed visitors' traditional spatial and temporal distributions in some parks, and has influenced visitors' perceptions and travel behaviours (Geng et al., 2024b). Studies found that COVID-19 has had impacts on long-term recreation monitoring, with new visitation patterns and travel behaviour, and renewed attention on greenspaces challenging existing management assumptions. (Fang et al., 2021; Ciesielski et al., 2024). A consequence of this shift in tourism visitation patterns due to the pandemic has been an escalation in the presence and severity of social and ecological impacts from tourism and local communities, which affects natural resources conservation outcomes (Ferguson et al., 2022).

A comprehensive understanding of the dynamics between visitors and places is essential for conducting tailored and effective analyses and planning for visitor management (Huettermann et al., 2019; Beritelli et al., 2020). Beritelli et al. (2020) presented three concepts regarding tourism management, including visitor flows, trajectories and corridors. Overall, ***visitor flows*** represent collective, similar experiences by multiple visitors, that occur either concurrently or sequentially. A ***trajectory*** is the path followed by visitors as they move toward a target destination, and is typically shaped by intermediate stops and environmental stimuli. Lastly, ***corridors*** are pathways that connect specific sites or objects (e.g., lakes, visitor centres) with activities (e.g., hiking, sightseeing) (Beritelli et al., 2020). In our study, both connected sites and activities were analysed to provide a deeper and more comprehensive understanding of the changes in visitor flows, trajectories and corridors during the COVID-19 pandemic.

Cross sectional ground surveys, interviews and field observations, have been the primary methods for national park tourism management research (Hull and Steward, 1995). Although these surveys have are useful for addressing specific research questions with tailored questionnaire designs, these methods may have temporal and spatial limitations, which makes it difficult to analyse the patterns of visitor distributions, behaviours and movements. The emergence and use of big data have been adopted by tourism researchers, which provides new opportunities to understand and analyse national park visitors (Vannette and Krosnick, 2018; Wilkins et al., 2021). Big data has three characteristics that provide significant advantages for its application in tourism management research (Russom, 2011): volume (scale), variety (types of data), and velocity (the speed at which data is generated, processed and analysed). Another notable advantage of utilising big data in tourism research lies in the opportunity to gather data before, during, and after events, which enables comparative analyses to investigate the effects of specific events on visitor behaviours and management strategies. Visitor big data (such as social media data) may facilitate exploratory methods and unanticipated results that have not been previously considered and measured (Vannette and Krosnick, 2018; Geng et al., 2024b). Research has validated the dependability of big data in the field of tourism research, along with its capability for achieving high levels of spatial and temporal resolution and accuracy, which are beneficial for nature-based tourism management and research (Walden-Schreiner et al., 2018; Barros et al., 2020). Furthermore, this study introduces a novel approach that integrates the Google Vision API with hierarchical clustering to classify visitor activity types across the pre, peri and post COVID-19 periods. In contrast to conventional spatial distribution analyses that primarily capture the geotagged data to visualize visitor spatial distribution, our method extracts not only geotagged location but also objects, activities, and themes from images to reveal activity patterns and associated temporal-spatial behaviour shifts. This enables a deeper and detailed analysis and understanding of visitor activities and behaviour shifts, especially in response to large-scale disruptions such as the COVID-19 pandemic.

However, limited research is available regarding the impacts of COVID-19 on visitor activities. This may be addressed by incorporating visitor big data to facilitate movement research within national parks. Most geotagged research primarily examines the temporal and spatial distribution of visitors. Also, there is limited research that has addressed visitor activities and their associated spatiotemporal patterns. This distinction is important, as visitors may go to the same areas, but engage in different activities, follow different itineraries, or demonstrate varying movement patterns. Three research questions were developed to address these knowledge gaps and frame this research:

1) What type of visitor activities were conducted in Banff, Jasper, Yoho and Kootenay National Parks based on Flickr images?
2) What are the changes in visitor activities and associated spatial distributions before and after the COVID-19 pandemic in four national parks?
3) What are the changes in visitor movement within individual national parks and across four national parks during the pandemic?

Addressing these questions will offer valuable insights to increase our understanding of visitor behaviour shifts before, during, and after the COVID-19 pandemic within Canada's national mountain parks. Furthermore, this analysis will aid in the strategic adjustment and allocation of park resources to effectively manage both short-term disruptions and long-term impacts of the pandemic on tourism.

2. Method

2.1. Study area

The study area includes Banff, Jasper, Yoho, and Kootenay National Parks (Fig. 1). Banff National Park (BNP) was the first national park in Canada and was established in 1885 and is 6641 km^2 in size. BNP welcomes over 4 million visitors annually, and is Canada's most visited national park, and the third most visited park in North America (Parks Canada, 2024a). Jasper National Park (JNP) is the largest national park in the Canadian Rockies and spans over 11,000 km^2 (Parks Canada, 2024b). In 2023, JNP received over 2.48 million visitors (Parks Canada, 2023). Yoho National Park (YNP), established in 1886 as the second-oldest national park in Canada draws approximately 663,000 visitors annually (Authentik Canada, 2024). Lastly, Kootenay National Park (KNP) was established in 1920 and receives 530,000 visitors annually (Parks Canada, 2024c). These four national parks were selected because BNP, JNP, YNP and KNP are ranked the top 1, 2, 6, and 7 most visited national parks in Canada (National Parks Traveler, 2023); therefore, tourism management is particularly important in these heavily visited national parks due to the impact of the pandemic. Given the geographical proximity of these four national parks, visitors often travel between them; visitor movements and activity patterns analysis can provide insight into broader regional tourism trends. Further, previous research has suggested that social media big data tends to serve tourism management research better in national parks that are more highly visited (Tenkanen et al., 2017; Kupfer et al., 2021). Lastly, limited research has been conducted on these four national parks, especially the Yoho and Kootenay National Parks.

2.2. Data collections

Established in 2004, Flickr is an online platform for people to share photos and videos and is one of the world's largest photo-sharing websites (Van Dijck, 2011; Tenkanen et al., 2017). Flickr is also the most popular platform for geolocated social media data for recreation and visitation studies (Ghermandi, 2022). The metadata of public geotagged posts from Flickr provides information about when photos were taken and where, along with other information such as captions and images, which can be collected through their Application Programming Interface (API) using Python scripts. An API is an intermediary software platform that allows different applications and websites to pull and integrate data (Lomborg and Bechmann, 2014). APIs provide functions

Fig. 1. Locations and Boundaries of the Four Canadian National Parks (Parks Canada, 2022).

to access data from third parties, reduce the complexity, perform tasks and extend the functionality, which can be a practical and useful tool for researchers to collect data for empirical research with its instantaneous and non-intrusive nature (Acker and Kreisberg, 2020).

Flickr data used in this research was collected from their API site using Python scripts (Flickr, 2024). In total, there were 15,096 records from the four national parks collected between 2019 - 2023. The data collected in each post included the post ID, user ID, title, description, tags, latitude and longitude, photo taken and upload time, geographical accuracy, and Uniform Resource Locator (URL). After reviewing all of the images collected from Flickr, and considering our focus on user-generated content, it is evident that Flickr, as a widely used platform among tourists for sharing experiences, provides a valuable source of visitor-generated content. Therefore, all the data collected within the selected national parks were considered to be visitation posts. Flickr was selected as one of our data collection sources for the following reasons. Firstly, Flickr has the ability to track visitor movement because its API allows to access and collect photos taken time and location, and people tend to post multiple pictures within one day or trip. Additionally, Flickr provides an API for unrestricted photo retrieval and aggregation (Huang, 2023).

2.3. Data analysis and interpretation

2.3.1. Google Vision API

The Google Vision API is a specialised service that uses deep learning algorithms and convolutional neural networks to identify huge datasets and numbers of images with high confidence levels (Chen and Chen, 2017; Google Cloud, 2024). The learning model is a powerful tool to identify objects, activities, themes, detect specific objectives and landmark, recognize and extract text within an image, which can ensure the content of large amounts of visual data remain relevant and organized (Chen et al., 2024a; Google Cloud, 2024). Its optical character recognition function can be used to understand the text within an image; landmark detection can identify related latitude and longitude, and entity detection can point out dominant objects within an image. We employed Google Vision API to generate labels and build visitor activity metadata on the images retrieved from Flickr. Fig. 2 provides an example of how Google Vision API generates labels from the input image.

2.3.2. Hierarchical clustering

Hierarchical clustering is an unsupervised machine-learning method that we conducted to cluster our Flickr photos into several groups based on their labels. It is a statistical method used to assess and group data samples into a series of clusters defined by similarity or distance (Chen et al., 2024b). Compared with the traditional reviews made by researchers, hierarchical clustering is more objective due to its data-driven approaches with high consistency and reproducibility with large dataset (Kaufman and Rousseeuw, 2009; Sebastiani and Perls, 2016). It also operates without a predefined number of clusters, thus providing flexibility in identifying patterns within the data structure based on mathematical and statistical measures. (Lee and Yang, 2009; Chen et al., 2024a). We adopted the Average Silhouette Score as a measure to determine the optimal number of clusters. This is a quantitative tool for assessing the quality of clustering that considers the similarity within the same cluster (i.e., cohesion) and the difference between different clusters (i.e., separation). The silhouette score ranges between −1 and 1, with values close to 1 indicating that the sample is well-matched to its

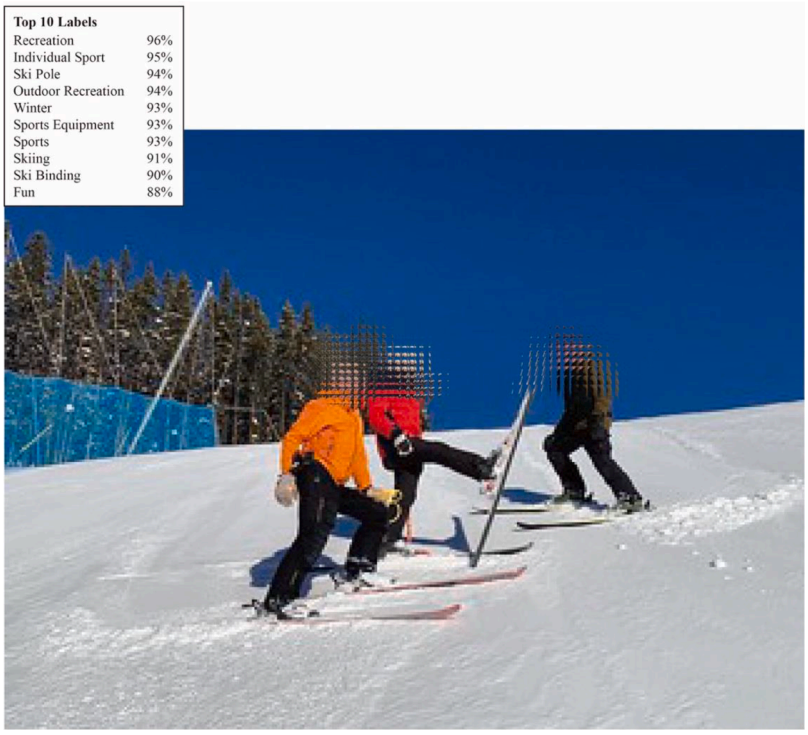


Fig. 2. Image labels generated by Google Vision API example.

cluster and poorly matched to neighbouring clusters (Chen et al., 2024a).

2.3.3. *Visitor movement and use patterns*

This research calculated the visitor movement using geotagged social media photos, where each photo taken, location, timestamp, and unique user ID were extracted to map and track visitor flow in one day within and towards national parks using Python script. Fig. 3 presents an example illustrating the movement of a single visitor movement during one trip in a time-space manner. Photo-user-day (PUD) was used in our approach, which is a measure that calculates the total number of visitors

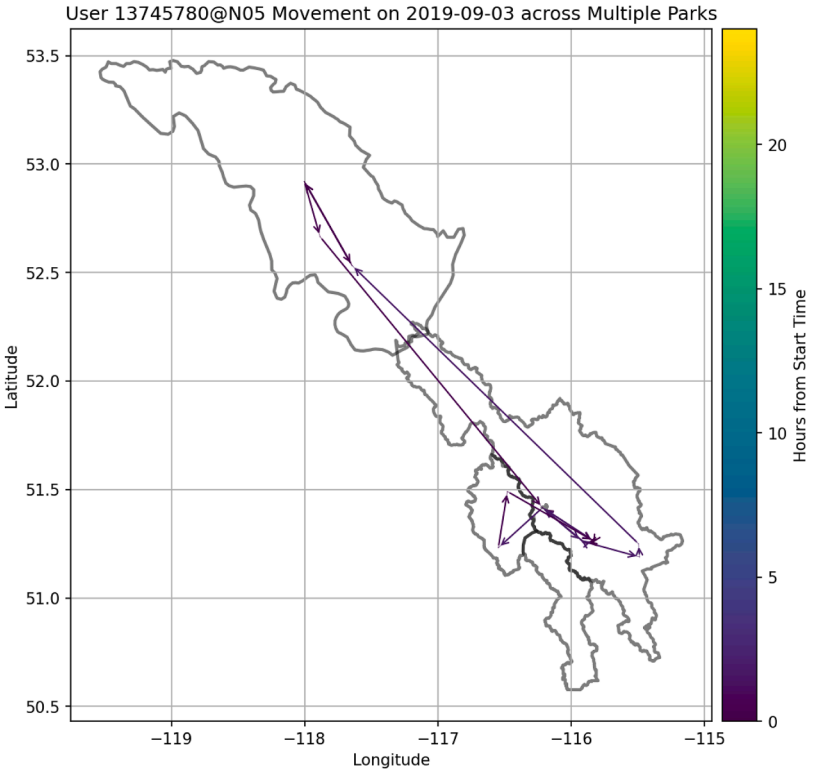


Fig. 3. Example of one Flickr user's time–space movement.

that took at least one photo on a unique day within a specific study area (Wood et al., 2013). In addition, usage patterns on roads and trails and traffic class were examined, with a particular focus on comparing pre-*peri*, peri-post and pre-post. Road and trail network data was retrieved from Open Street Map (OSM, 2024). Traffic class and usage patterns were analysed under R version 4.2.2. using the sf packages (v.1.0–9; Pebesma, 2018).

3. Results

3.1. Activity labels and clusters identification in the four national parks

Cluster analysis revealed that the data partitioned into 10 clusters achieved the highest silhouette average score, representing the accuracy of image labels' structure and patterns. The outcome of the hierarchical clustering is shown in Appendix A. The top ten labels of each cluster were also generated by employing Google Vision API in order to identify visitor activity types, thereby enhancing comprehension and interpretation of the distinct clusters and further spatial analysis. Each cluster represents unique characteristics of visitor activity in the selected four national parks.

After clustering the Flickr visitor images and labelling the cluster, we assigned an activity name for each cluster by manually browsing images in each cluster. Table 1 shows each cluster, top labels, and representative photos. Cluster 0, flora and fauna watching activities, includes images that exhibited the distinctive characteristics of plants and wildlife, such as mountain goats, deer and wildflowers. The images in Cluster 1, snow-based sightseeing and activities, depict the unique activities of snow-related adventure, including skiing, snowboarding, and snow-based sightseeing in high-altitude mountainous regions. Cluster 2 includes images featuring lake and mountain sightseeing-related activities and refers to the photos with the unique traits of encompassing lake and mountain elements coexisting in the landscape. Cluster 3 represents cultural and natural interpretation, which includes unique traits of indoor activities, including both cultural and natural performances (such as museums) and social entertainment (such as music showcases in bars). Cluster 4, highland mountain sightseeing and hiking, refers to the outdoor activities that involve highland mountain geographical characteristics. The images in Cluster 5 include road viewing and pictures of people, suggesting the activities of road trip sightseeing and photographing famous landmarks with a special focus on people in the image. Cluster 6 contains images that are indicative of fluvial landforms and streams sightseeing, and images in Cluster 7 shows waterfall sightseeing. Cluster 8 represents small vehicle-based activities such as motorcycling and car riding. Lastly, Cluster 9 shows railed vehicle recreation, referring to train-based sightseeing. Fig. 4 shows the detailed results of the 10 clusters by word cloud and frequency of labels.

3.2. Changes in visitor activities in the four national parks from 2019 - 2023

After identifying the cluster type for each category of Flickr images, a temporal analysis was performed to explore the impacts of COVID-19 on visitor activity within four selected national parks based on the Flickr's posts. Fig. 5 illustrates the change in cluster counts from 2019 to 2023. Overall, there was an initial decline in the aggregate volume of Flickr posts following the onset of the COVID-19 pandemic across the four national parks. The volume of posts increased in 2022, and declined slightly in 2023. Fig. 5b depicts the percentage change of each cluster during the pandemic. In general, the number of Flickr users' photographs became less equally distributed among the ten clusters between 2019 - 2023. In 2023, the top three activities captured in Flickr photos were lake and mountain sightseeing (23.3 %), highland mountain sightseeing and hiking (18.6 %), and fluvial landforms and streams sightseeing (13.5 %), representing 55.4 % of the total activities in the four national parks.

With respect to identifying changes in visitor activities based on Flickr's posts, Cluster 2 activities (lake and mountain sightseeing) had the largest number of images among the ten activity types in 2019, 2021 and 2023, with a slight decline in percentage in 2020, and reached its highest percentage in 2023, representing 23.3 % of the total Flickr image. Cluster 4 photos, highland mountain sightseeing and hiking experienced an increase in percentage in 2020, decreased in 2021 and 2022, and had a notable increase in 2023. Clusters 8 (vehicle-based images) and 9 (train-based activities and touring) have exhibited minimal changes since the onset of the pandemic with low cluster percentages.

Fig. 5c illustrates the tourism seasonality in visitation and activity in the four national parks of Flickr posters. Our study area generally had significantly higher image numbers during the summer season from 2019 - 2023, with cluster 0 (flora and fauna watching) and other sightseeing-based clusters as dominant activity types. During the winter season, cluster 1 (snow-based sightseeing and activities) and cluster 9 (train-based activities and touring) became the dominant subjects of photographs. Flickr post data suggests that park tourism seasonality was mitigated, based on Flickr users' posts, by an increased park visitation between January to June, which was typically the off-season in these national parks pre-COVID-19 pandemic.

3.3. Change in Flickr users' activities from a spatial perspective under the COVID-19 pandemic

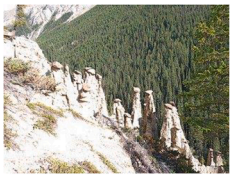
Fig. 6 shows the changes in the subjects of Flickr photographs by clusters in the four national parks from 2019 to 2023. In 2020, Banff National Park had the most significant decline in posted photos, with visitors shifting towards remote areas where cluster 0 and cluster 1 were the dominant activities. Cluster 5 became the dominant activity in the Town of Banff. In Jasper National Park, the total number of activity posts and spatial distribution did not significantly change, with train-based activity remaining dominant cluster in the Municipality of Jasper. Compared to pre-COVID-19, there was less activity at Maligne Lake and more flora and fauna activity conducted at the Jasper Lake Sand Dunes area. Yoho National Park's Flickr posts exhibited similar spatial distribution but different activity types after COVID-19 started. There were more cluster 0 activities, especially at Emerald Lake. Kootenay National Park received significantly more visitors in the Marble Canyon area, with the dominant activities of cluster 4, 5 and 6, while Stanley Glacier Trailhead in the northern part received more visitors. In 2021, Banff National Park had increased visitors near the Egypt Lake area with cluster 4 activity. Yoho National Park exhibited more activity cluster numbers and diversity near the O'Hara Lake areas, including all clusters except cluster 9. Kootenay National Park experienced significantly fewer visitors, especially in the southern part, based on Flickr posts.

Between 2022 and 2023, four national parks received more visitors based on the posts. Specifically, Jasper National Park received more visitors in the southern area of the park, with clusters 1, 2 and 8 as the major activity types. In 2023, Yoho National Park received more photographs in the Yoho River areas of sightseeing streams and waterfalls, whereas Emerald Lake and O'Hara Lake received more visitors in 2022, with the dominant activities of clusters 2 and 6. The overall quantification of the shift direction in cluster centroids for pre-peri, peri-post and pre-post comparison is shown in Appendix B.

3.4. Changes in Flickr user movement in the four national parks from 2019 - 2023

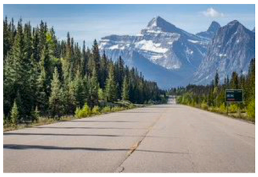
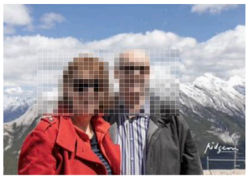
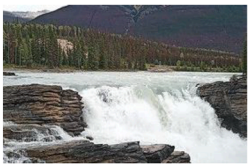
Individual visitor movement paths were generated by using unique user IDs. Fig. 7 illustrates the daily movement patterns based on Flickr users' posts, represented by nodes and lines. Nodes signify point of interest (POIs), with their size indicating the number of Flickr user posts. Lines represent the movement of visitors between POIs, with their thickness corresponding to the number of visitors traveling between two

Table 1
Social media clusters, top labels, and representative photos.

Cluster	Top Labels	Proposed Tag	Representative Photo from Flickr	
Cluster 0	Plant, natural landscape, tree, grass, landscape, terrestrial plants, wood, groundcover, terrestrial animal, trunk	Flora and Fauna watching (FAFW)		
Cluster 1	Mountain, sky, snow, landscape, slope, cloud, natural landscape, freezing, terrain, geographical phenomenon	Snow-based sightseeing and activities (SBSA)		
Cluster 2	Sky, mountain, water, natural landscape, cloud, lake, highland, landscape, plant, tree	Lake and mountain sightseeing (LAMS)		
Cluster 3	Wood, plant, landscape, bedrock, font, outcrop, formation, event, water, building	Cultural and natural education (CANE)		
Cluster 4	Sky, mountain, natural landscape, plant, tree, cloud, larch, landscape, highland, slope	Highland mountain sightseeing and hiking (HMSK)		

(*continued on next page*)

Table 1 (*continued*)

Cluster 5	Sky, plant, tree, cloud, mountain, road surface, asphalt, natural landscape, building, travel	Road viewing and human selfie (RVRS)		
Cluster 6	Water, natural landscape, sky, mountain, plant, tree, cloud, larch, lake, fluvial landforms of streams	Fluvial landforms and streams sightseeing (FLSS)		
Cluster 7	Water, fluvial landforms of streams, natural landscape, watercourse, waterfall, plant, bedrock, water resources, landscape, tree	Waterfalls sightseeing (WS)		
Cluster 8	Vehicle, sky, wheel, tyre, motor vehicle, cloud, car, plant, mountain, tree	Vehicle-based activities (VBA)		
Cluster 9	Train, rolling stock, vehicle, sky, track, tree, plant, railway, cloud, mountain	Train-based activities and touring (TBAT)		

POIs within a single day. Before COVID-19 started, the corridors between the Town of Banff, Lake Louise, Athabasca Glacier, and Jasper townsite covered the majority of Flickr users' movements in one day. After COVID-19 started, Banff and Jasper National Parks had significantly less connected Flickr user movement. In contrast, movement between Banff and Yoho National Parks became more interconnected, indicating that Flickr users tended to visit both parks during their daily itinerary. Appendix C visualises the individual Flickr user movements in the four national parks and the associated changes between the pre-, peri and post-COVID-19 pandemic. After COVID-19 started, four national parks received significantly less daily travel between national parks based on Flickr users' posts, especially between Banff and Jasper National Parks, and daily long-distance travel resumed in 2023. Kootenay National Park received significantly less movement after COVID-19 started, especially in the southern part of the destination. Based on the Flickr images, northern Kootenay National Park received more visitation after the pandemic, with the new daily movement patterns between the Town of Banff in Banff National Park and Marble Canyon in northern Kootenay National Park. Combined with the results of the spatial distribution of visitor activity, the movement findings can also give us a deeper understanding of the motivation that drives Flickr user movement.

3.5. Changes in Flickr user movement, traffic class, and most frequented roads/trails in the four national parks from 2019 - 2023

After analysing the visitor flows of Flickr users in the four Canadian National Parks, changes in traffic patterns and road/trail usage from 2019 to 2023 were examined using Flickr posts to provide reference for park management. First, the top five roads and trails were selected to conduct a focused and comparative analysis. Fig. 8 compares the number of users on selected roads and trails in the four national parks from 2019 to 2023. The top five most used roads were Banff Avenue, Bow Valley Parkway, Icefields Parkway, Trans-Canada Highway and the Yellowhead Highway. There is a notable decline in Flickr posts numbers for most roads from 2019 to 2020. Some recovery is visible from 2021 to 2023, particularly on Icefields Parkway, which shows a significant increase in usage in 2023. However, the impacts of COVID-19 on some road usages are not transient, such as Bow Valley Parkway and Banff Avenue. Trans-Canada Highway and Yellowhead Highway exhibited similar trends, with a sharp decrease in usage in 2020 and then a significant increase in 2022.

The top 5 most frequently used trails included Bow Glacier Fall Trail, Johnston Canyon Trail, Lake Agnes Trail, Larch Valley Trail, and Plain of Six Glaciers Trails. A similar decline is seen from 2019 to 2020, with the number of Flickr posts related to the Johnston Canyon Trail and Plain of Six Glacier Trail showing a notable drop. However, Lake Agnes Trail showed a continuous increase since 2019. By 2023, most trails continued to record lower user posts compared to 2019, with the notable exception of the Bow Glacier Falls Trail, which experienced higher usage by Flickr users than its pre-pandemic levels.

To provide a comprehensive overview of the changes, all roads and trails across the four national parks were analysed. As shown in Fig. 9, overall traffic volume of Flickr users declined after COVID-19 started. In

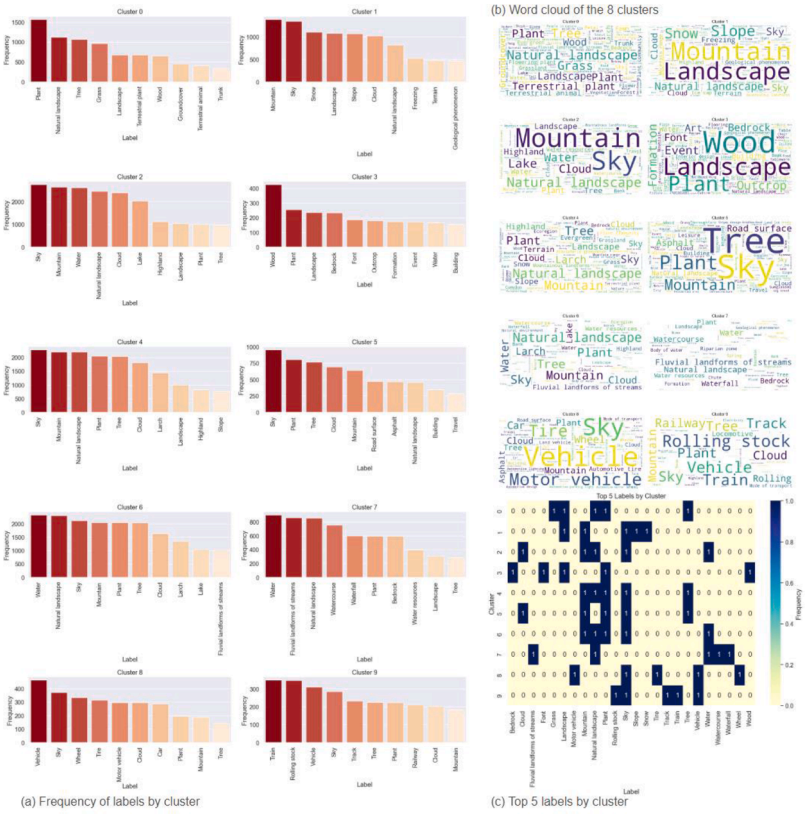


Fig. 4. Word cloud and frequency of labels by cluster.

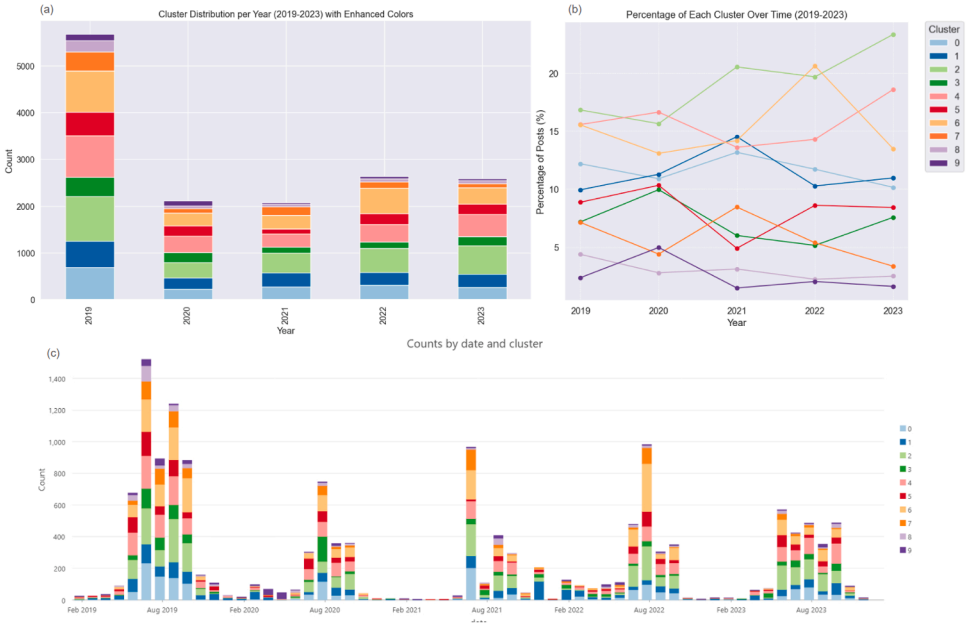


Fig. 5. Changes in Flickr user activity from 2019 - 2023.

2019, roads such as the one connecting the Town of Banff to Lake Louise and the route from the Columbia Icefield to Sunwapta Falls experienced the highest traffic levels. However, post-COVID-19, areas like the road between Lake Louise and Peyto Lake, along with the Moraine Lake region had increased traffic. By 2021, most areas exhibited low to medium traffic levels, except Johnston Canyon area in BNP. Starting in 2022, traffic volumes began to rise, particularly in areas like Lake Louise, the region shared by Banff, Yoho, and Kootenay National Parks, Kootenay Valley Viewpoint, Radium Hot Springs, Columbia Icefield Parkway, the route between Athabasca Falls and the Municipality of Jasper, and Highway 16 in the north-eastern part of JNP. By 2023, KNP experienced significantly higher traffic levels, especially on Route 93S between Marble Canyon Trailhead and Vermilion Crossing. High traffic was also recorded on the Bow Valley Parkway to Lake Louise and Columbia Icefield Parkway.

Fig. 10 focuses on the changes in the traffic class with pre-peri,

Fig. 6. Changes in Flickr user activity spatial distribution from 2019 - 2023.

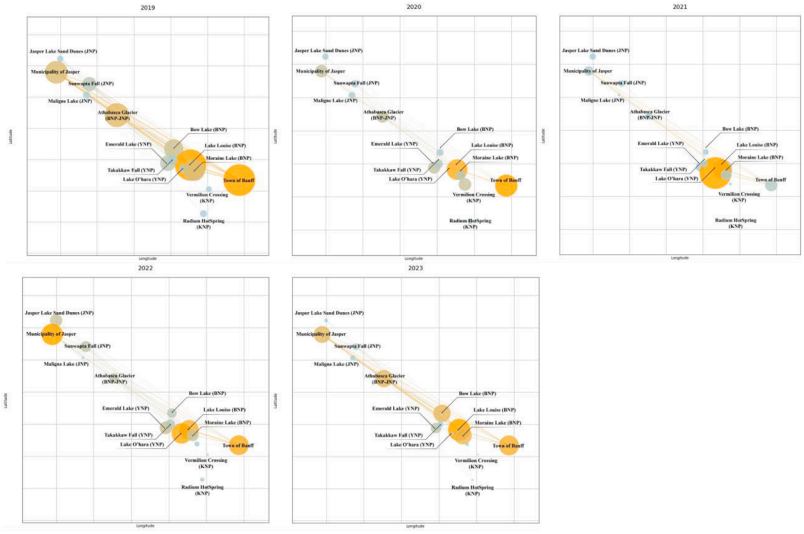


Fig. 7. Changes in Flickr users' daily movements in four national parks.

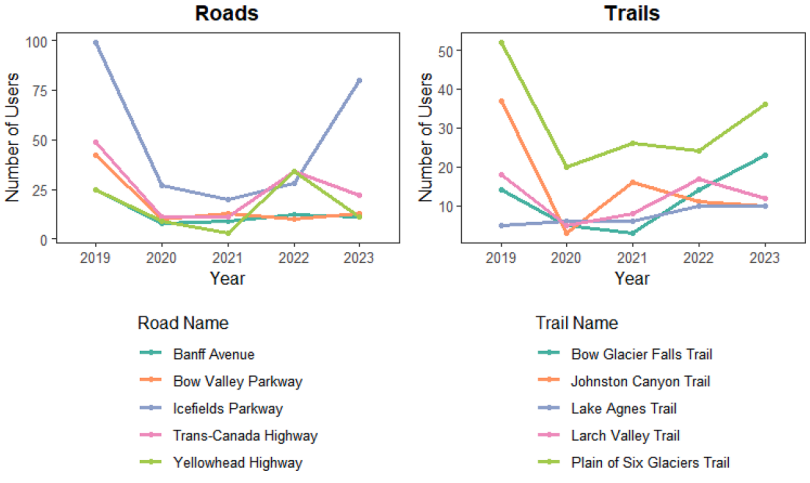


Fig. 8. Changes of the top 5 roads and trail usage from 2019 - 2023 in four national parks.

Fig. 9. Traffic class and road/trail usage from 2019 - 2023 in four national parks.

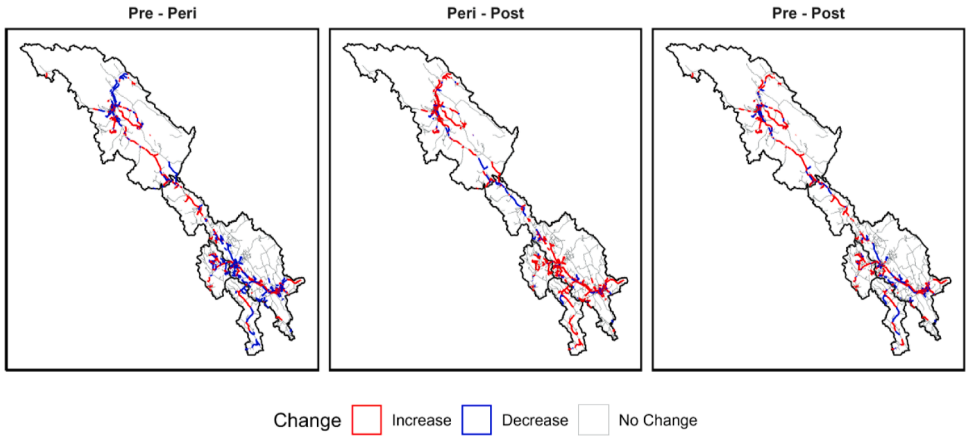


Fig. 10. Changes in traffic class in four national parks.

peri-post and pre-post comparison. In the pre-peri comparison, several roads and trails showed significant decreases in traffic, particularly those roads and trails around or connecting traditionally popular tourism attractions such as the Town of Banff, Lake Louise, Columbia Icefield, Radium Hot Springs, Emerald Lake, and Northern Jasper National Park. One highlight of the finding is that the pre-peri and peri-post results are mostly reversed, indicating that some of the roads and trails' traffic patterns observed are largely transient and reversed once the restrictions were lifted. However, the comparison between 2019 (pre-COVID) and 2023 (post-COVID) shows persistent decreases in traffic on certain roads and trails, including the route connecting the Town of Banff and Bow River, as well as the Columbia Icefield area. Conversely, certain areas such as the route from Marble Canyon to Vermilion Crossing day-use area in Kootenay National Park, Emerald Lake Road, and the TransCanada Highway between Field and Lake O'Hara saw increased usage among Flickr users in 2023 when compared to pre-pandemic levels.

4. Discussion

4.1. *Impacts of COVID-19 on national Flickr users' activity types*

The COVID-19 pandemic has significantly shifted travel activities, movement and decision-making of participating in outdoor activities (Humagain and Singleton, 2021a; Mateusz and Monika, 2021; Ferguson et al., 2023). However, limited research has been conducted to investigate the changes in national park visitor activity type and its spatial distribution, as well as associated movement shifts under the context of the COVID-19 pandemic. We introduced and applied a framework for determining Flickr users' activity type by using social media photos and computer vision techniques. We identified ten distinct clusters that delineated unique aspects of Flickr users' activities within national parks, which is a foundational contribution of this research.

The temporal analysis of Flickr user posts demonstrated congruence with official park visitor attendance data from 2019 – 2023. This alignment suggests that Flickr data can serve as a reliable indicator for analysing visitation patterns and informing tourism management

strategies in national parks. Based on our temporal analysis, one of the key findings is that cluster 2 (lake and mountain sightseeing) had the highest percentage of Flickr images from in 2019, 2021 and 2023, with the peak at 23.3 % in 2023. This can be explained by the unique characteristics of Canadian Rocky Mountain National Parks, which are renowned for the aesthetic beauty of trees, mountain forests and lake landscapes (UNESCO, 2024). Prior studies have determined that visitors' perceived risk of infectious diseases significantly influences their travel plans and behaviour (Cahyanto et al., 2016; Rahman et al., 2021), with increasing visitors tended to choose attractions with open spaces and good air circulation after COVID-19 started (Geng et al., 2024b). Another notable increase in activity type after COVID-19 started is hiking and highland sightseeing (cluster 4), which may be explained by the growing preferences and perceived importance for remote, immersive, and physically active experiences during the pandemic (Smith et al., 2023; Geng et al., 2024b). Conversely, indoor or social activities decreased, such as cultural education and selfies at famous landmarks (clusters 3 and 5).

Additionally, the change in Flickr users' activities may be explained by the general shift of travel motivations during the COVID-19 pandemic. Previous studies have shown increased demand for natural and forested environments, as parks can benefit people's mental and physical well-being during health crises (Derks et al., 2020; Grima et al., 2020; Soga et al., 2021). Based on a focus group study conducted by Humagain & Singleton (2021b), the top three travel motivations for outdoor recreational trips were "novelty experience", "enjoy nature", and "escape personal-social-physical pressure". Another case study of the impacts of COVID-19 on national park visitor travel motivation in Banff National Park also showed that pressure reduction emerged as the increasing motivation factor after COVID-19 started (Geng et al., 2023). Overall, this marked shift highlights the critical importance of forested areas in providing psychological restoration, stress relief, and overall enhancement of physical and mental health during health crises such as COVID-19 pandemic.

4.2. Impacts of COVID-19 on Flickr users' activities and spatial patterns in the four Canadian national parks incorporating visitor flow

The analysis of visitor activities through Flickr posts (2019–2023) reveals significant spatial and behavioural shifts in how Flickr users engaged with four national parks during the COVID-19 pandemic. Photos show increased diversity in activity types and locations, with more highland hiking, snow-based recreation, and visits to remote areas. ***This emerging trend continued into the post-COVID-19 period, which suggests long-term impacts of the pandemic on visitor travel behaviour.*** This may be explained by the new normal that visitors prioritised physical distancing and nature immersion over traditionally popular tourist hotspots (Templeton et al., 2021; Ferguson et al., 2023). Banff National Park experienced the most pronounced changes in visitor activity during 2020. The overall reduction in visitor activities, particularly in traditionally popular areas, reflects the broader global tourism trend where travel was significantly curtailed due to the pandemic (Mateusz and Monika, 2021; Templeton et al., 2021).

From a spatial perspective, the increase in flora and fauna photographs (cluster 0) and snow-based photos (cluster 1) in remote areas highlights a shift toward activities that allow visitors to engage with nature while maintaining physical distance from others. This aligns with study showing increased nature-based activities during the pandemic as people sought out solitude and natural beauty experiences in wilderness areas (Ferguson et al., 2022). This may be explained by the different visitor demographics and travel motivations shifted by the COVID-19 pandemic: the restrictions of international travel, national parks, especially previously heavily visited ones such as BNP, were associated with significantly fewer international visitors (Mertz, 2020; CBC, 2021; Geng et al., 2023). Research has shown that local visitors are more likely to have more than one previous visit, making them more inclined and confident to explore a variety of tourist attractions beyond the traditional popular hotspots, whereas international first-time visitors are more likely to rely on visitor guides and social media and visit signature tourist attractions (Palso et al., 2009; CBC, 2021; Geng et al., 2024b).

4.3. Impacts of COVID-19 on Flickr user movement, park and road usage, and visitor activity spatial distributions and associated motivations

The COVID-19 pandemic caused significant fluctuations in road and trail usage within national parks, which reflected broader changes in visitor uses, traffic patterns, park infrastructure and facilities demand, and resource adjustment. Our analysis demonstrated both temporary and more persistent shifts in Flickr users' movement patterns based on traffic volumes and usage patterns. The initial decline in road and trail usage during 2020, followed by a gradual recovery in 2021 and a resurgence in 2023, corresponds with global tourism patterns. Before the pandemic started, the tourism corridor between the Town of Banff and Lake Louise received a high traffic class among Flickr users, whereas under the COVID-19, this specific corridor received a notable lower traffic class, and this new trend continued to post-COVID-19 period. This suggests that **COVID-19 may have helped to alleviate the imbalance in visitor distribution and usage patterns, particularly in heavily frequented national parks. Some usage patterns that changed during the pandemic were neither temporary nor reversible.** More specifically, the pandemic prompted shifts in visitor travel motivations and behaviours, such as seeking more health-related services, increased travel motivation in stress reduction, and preferring remote areas for outdoor activities (Kruczek et al., 2023; Seyfi et al., 2024). Consequently, some roads and trails can help attract more usage, alleviate traffic congestion and reduce overcrowding in traditionally popular tourism corridors.

Flickr data reveals that road and trail usage has shifted during the pandemic. For example, in KNP, a new high-traffic corridor was formed between Marble Canyon Trailhead and Vermilion Crossing, replacing its pre-COVID-19 low traffic status, likely due to the shift in visitor travel motivation and demographics as previously mentioned. While the traffic class for most roads and trails decreased in the pre- to peri-pandemic comparison, the route connecting the Columbia Icefield to the Municipality of Jasper experienced increased Flickr user visitation. Notably, post-COVID-19 usage of this route has surpassed pre-pandemic levels. This is consistent with the Jasper National Park Annual Report, that reported annual visits had a fast recovery rate, with visitation levels in 2023 surpassing those of the pre-COVID-19 period (Parks Canada, 2023). Tourism Jasper responded promptly to the challenges posed by COVID-19 by implementing strategies to boost visitor motivation and increase park visitation. For example, Whistlers Campground, the largest campground in Parks Canada's national system, reopened in July 2021 following significant facility upgrades, including improved sanitation facilities. This 781-site campground has effectively accommodated the growing demand for camping options during the COVID-19 pandemic (Gibson, 2021; Cairn Consulting Group, 2022). Lastly, the reversal of the traffic usage patterns of certain roads and trails between the pre-peri and peri-post periods underscores the adaptability of Flickr users' responses to external conditions, and highlights the differential recovery rates across national parks. Understanding which usage patterns have recovered and which have been permanently affected by COVID-19 is essential for effective post-COVID-19 park management and for enabling rapid and effective responses to future potential health crises.

4.4. Management implications and recommendations

A comprehensive understanding of changes in visitor activity types, spatial distribution, tourist movement, usage patterns, and park traffic classifications in the context of the COVID-19 pandemic is essential for effective and sustainable park management. Tourism behaviour reflects

not only tourism industry activities such as park resource allocation and public transportation planning but also reveals potential tourism impacts on park ecological integrity and wildlife (Mckercher and Lau, 2008; Hu et al., 2019). We identify targeted management implications and recommendations for park managers. While this study focused on four Canadian Rocky Mountain National Parks, the inclusion of study areas with differing visitation rates, visitor demographics, and behavioural dynamics allows the findings to be both practically relevant and generalizable to a wide range of national parks and other protected areas worldwide. For instance, the findings from Banff National Park, which attracts a substantial number of international visitors, can be considered representative of heavily visited national parks and forested areas that typically serve as globally recognized tourism destinations. In contrast, Kootenay National Park, characterized by lower visitation rates and predominantly local visitation, may provide insights more applicable to less-visited parks that has more local or regional visitors. Recognizing these visitor profile distinctions enables park managers and policymakers to effectively contextualize and generalize our findings to parks or forested areas with similar visitation patterns and management challenges, particularly in preparing for and responding to health crises across diverse park types.

4.4.1. *The shifts in visitor activities and associated tempo-spatial distributions present both challenges and opportunities for park management*

The shifts in Flickr user activity and movement observed in this study have several important implications for national park management. First, the increase in nature-based activities in lakes, mountains, and highlands, and the increased preferences for remote, less-developed areas, highlights the need for adaptive resource allocation and management. For example, BNP had more Flickr posts near the Egypt Lake area with cluster 4 (HMSK) activity, YNP exhibited more activity cluster numbers near the O'Hara Lake areas after COVID-19 started. These examples suggest a need to adapt local services by implementing sustainable, low-impact and information facilities, such as portable washrooms and safety warning boards, to accommodate visitor demand while minimising environmental impact.

The increased visitation to newly formed tourism hotspots, such as Marble Canyon and Stanley Glacier, presents unique management challenges. These areas, which previously received fewer visitors, now face the potential for environmental degradation due to increased footprint. To effectively manage increasing visitation to these areas, it is important to implement adaptive strategies. These strategies could include enhancing trail maintenance, conducting carrying capacity analyses, establishing comprehensive visitor education and interpretation programs, implementing proactive monitoring systems, and developing robust waste management practices. Developing collaborative partnerships among stakeholders is crucial for preserving the ecological integrity of these areas, as it facilitates resource-conservation effort, improves resources sustainability and promotes visitor environmentally responsible behaviour (Dangi and Gribb, 2021). Having a deeper understanding of the specific types of visitor activities conducted in these areas will enable the development of a tailored management plan.

This spatial reorientation raises questions about the long-term resilience of national park ecosystems to accommodate shifting visitor patterns. The movement toward more isolated and ecologically fragile areas requires a reconsideration of park zoning policies and systems, particularly in those areas not originally designed to accommodate high volumes of visitors. Studies have suggested the integration of dynamic zoning, where certain areas are periodically closed or restricted based on visitor load and ecological sensitivity, to mitigate long-term damage (Tenkanen et al., 2017). Furthermore, post-pandemic tourism management also needs to take into consideration regarding this trend and ensure that conservation goals are not compromised by the dual pressures of recovery and increased visitation.

On the other hand, the new normal regarding visitor activity patterns also presents opportunities for park management. This shift provided an opportunity for ecological recovery for some traditionally overcrowded areas such as Lake Louise. Additionally, our findings indicate that the COVID-19 pandemic may contribute to mitigating the spatial and temporal imbalances in visitor patterns within national parks. Therefore, it is important to utilise and keep its transformative strength to solve some historic issues, especially in heavily visited national parks.

Lastly, national parks are increasingly recognized as therapeutic landscapes rather than just recreational spaces, with the pandemic reinforcing their roles as essential green infrastructure. There are several reasons why national parks and forested areas serve as exceptional therapeutic landscapes, particularly in the context of health crises. They encompass diverse green and blue spaces, such as mountains, forests, and lakes, which have been linked to reduced stress, improved mood and sleep quality, reduced sense of isolation, and lower blood pressure. Thus, it reduces the risk of depression and anxiety, while enhancing individuals' resilience and capacity to manage life tasks effectively (Hammen, 2005; Roe and Aspinall, 2011; Cox et al., 2017; Fong et al., 2018; Bratman et al., 2019; White et al., 2019; Geng et al., 2021). These natural settings also engage the five senses (sight, smell, taste, hearing, and touch), and these sensory organs convey information to brain, enabling individuals to interpret and perceive their external surroundings, and reduce the negative impacts of the pandemic on people's mental and physical health (He et al., 2022). Also, national parks, particularly in remote forested areas, have high air quality with enriched oxygen levels, as well as regulated environmental temperature and humidity, which can enhance overall comfort and benefit visitors' health. Additionally, national parks provide safe spaces for people to have social distance without social disconnection. More specifically, under the context of health crises, parks allow visitors to maintain social connections while still following health guidelines, thus reducing the negative feelings of loneliness and isolation (Geng et al., 2021).

This recognition extends to healthcare, as seen in Canada's PaRx program, which allows doctors give personalised "nature prescriptions" (McSheffrey, 2022). Parks Canada also supports this initiative by providing free Discovery Passes to patients with the prescriptions (CBC, 2022). With growing travel motivation of stress reduction (Geng et al., 2023), there is an opportunity to rethink national park marketing and tourism planning from the lens of a therapeutic landscape perspective. Collaboration among park managers, ecologists, architects, soundscape specialists, medical professionals, psychologists and related experts is crucial for developing sustainable, nature-based tourism. This multidisciplinary approach prioritises environmental preservation and visitor well-being, particularly in light of the pandemic and future health crises, ensuring parks serve as accessible refuges supported by responsive management strategies.

4.4.2. *An integrated transit system between national parks is needed*

Our findings indicate increasing visitor flow connectivity between Banff, Yoho, and Kootenay National Parks after COVID-19 started. This suggests that visitors are increasingly treating these parks as an interconnected landscape. **However, currently there is no transit system connecting these three national parks, indicating that access to certain areas within the parks is limited to visitors who choose to travel by personal vehicle or through a tourism agency.** This underscores the need for integrated transit system planning across these four national parks. Parks Canada has implemented some public transit solutions for popular areas within Banff National Park to reduce car dependency and provide alternative access to key sites (Parks Canada Agency, 2022). However, there is no transit between these three national parks. There are several benefits to the park transit system. First, it is critical to manage visitor flows in large protected areas, which can distribute traffic away from congested areas and toward less frequent but newly developed hotspots. For example, there has been a 71 % increase in traffic volume over the past decade around the Lake Louise area, which has caused significant congestion problems and parking issues (Parks Canada Agency, 2022). Therefore, a transit bus connecting

Lake Louise in BNP and Marble Canyon in KNP (a 30-minute drive) could alleviate overcrowding and reduce the ecological burden in Lake Louise. This service would attract more visitors to lesser-known parks, distributing tourism more evenly and supporting broader economic benefits. Secondly, a well-managed park transit system can contribute to both visitor experience and transportation-related greenhouse gas emission reduction, thus achieving an environmentally and economically sustainable future for parks and solidifying Parks Canada's reputation as a global leader. Lastly, the pandemic exposed the vulnerabilities of some park infrastructure, particularly in KNP, where limited connectivity to other parks exacerbated declines in visitation after COVID-19 started. Therefore, a transit system can reduce the recovery time post-pandemic, especially for less visited national parks.

It is worth noting that the proposed transit system must align with the management plans of each national park while ensuring the protection of natural resources. This will require careful consideration of local carrying capacities, infrastructure and facility maximum occupancy, visitor experience, and ecological objectives. Collaboration and improved integration among the stakeholders of the various national parks will support these objectives. This approach will ensure that current and future visitors can navigate within and between parks in an accessible, inclusive, and comfortable manner while keeping Parks Canada's mandate to protect the ecological integrity of national parks.

4.4.3. COVID-19 impacts on usage patterns may not be temporary

Our findings suggest that the changes in Flickr users' travel behaviours, activities and usage patterns are not all temporary; some new normal patterns persist even till the post-COVID-19 period. This underscores the need to manage national parks and tourism through the lens of a health crisis perspective. Going forward, park managers may need to reconsider the zoning system within national parks to adjust to the new normal and future health crises, incorporating ecological assessment, public consultation, as well as monitoring and planning reviews. Secondly, policies and actions supporting public health require a deeper understanding of visitor activities and movement. Quantifying visitor flow incorporating space and time is important for understanding the processes and factors that shape the park's recreational use (Liu et al., 2017).

However, collecting ground survey data on visitor flows and activities within national parks from a time-space perspective can be challenging. Currently, Banff National Park lacks dedicated resources for gathering and analysing social science data, despite its critical role in park marketing and visitor management. As noted by Parks Canada Agency (2022), visitor attendance metrics are significantly outdated. This gap results in insufficient information to comprehensively understand visitor patterns, motivations, and behaviours. Meanwhile, big data can serve as a valuable information source to assist and support decision-making. As visitor preferences and behaviour continue to evolve in the post-pandemic era, park managers could benefit from the combination with visitor ground survey and social media data to monitor trend and adjust management strategies accordingly.

5. Conclusion

We examined the impacts of the COVID-19 pandemic on Flickr users' activities and movement patterns from a time-space perspective in Canadian Rocky Mountain National Parks. Firstly, the visitation trend of Flickr user posts based on temporal analysis is aligned with official park visitation data from 2019 – 2023. This alignment suggests that Flickr data can serve as a reliable reference for tourism research and management. Our findings highlight that the pandemic has substantially shifted Flickr user travel activities, movement and decision-making while engaging in national parks, and some new patterns persist in the post-COVID-19 period, indicating some changes are not transient. Overall, Flickr users have been engaged in more types of activities, such as lake and mountain sightseeing and highland recreational activities in national parks, after COVID-19 started, especially in remote and less traditionally popular areas. Our findings suggest a growing trend towards connectivity in visitor movement between Banff, Yoho and Kootenay National Parks after COVID-19 started.

These findings underscore the need to manage national parks and tourism through the lens of a health crisis perspective. With parks and greenspaces receiving renewed attention after COVID-19 started and more people viewing national parks not only as recreational spaces but also as therapeutic landscapes, park managers should consider implementing policies and actions that better support public health for the post-COVID-19 period and future crises. These implications extend beyond the current pandemic; we provide management implications and recommendations regarding how to better cope with future health crises by managing park resources and tourism effectively and promptly, incorporating both ecological conservation and public well-being.

One limitation of our study is that while social media big data has many advantages, it also has issues such as capturing representative information from park visitors. Future research could use ground surveys to compare, validate, and integrate big data to increase accuracy. As we move through the post-COVID-19 period, future studies will continue monitoring visitor travel behaviour patterns at a more detailed and dynamic scale.

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CRediT authorship contribution statement

Dehui Christina Geng: Writing – original draft, Visualization, Validation, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Mingze Chen:** Writing – review & editing, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation. **Harry Seely:** Writing – review & editing, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation. **Howie W. Harshaw:** Writing – review & editing, Validation, Resources, Methodology, Investigation, Conceptualization. **Christopher Gaston:** Writing – review & editing, Validation, Resources, Investigation, Conceptualization. **Wanli Wu:** Writing – review & editing, Validation, Resources, Investigation, Conceptualization. **Guangyu Wang:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

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

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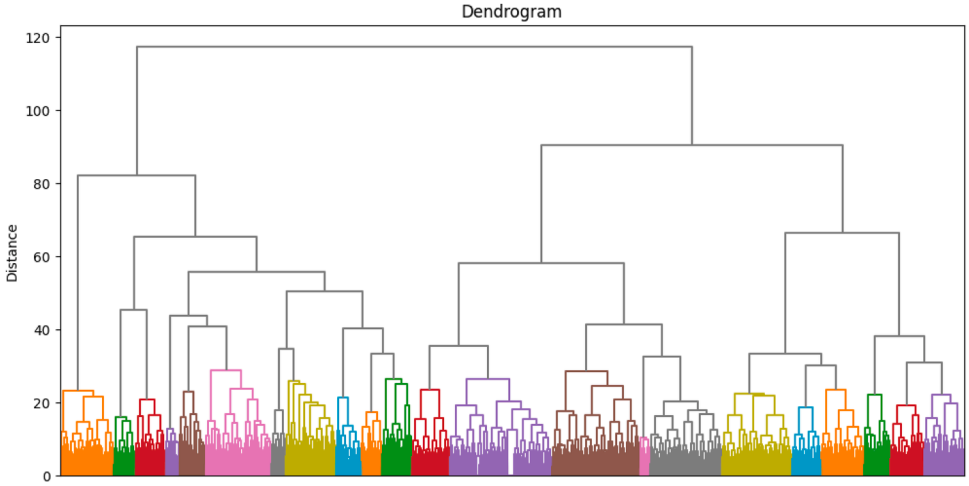
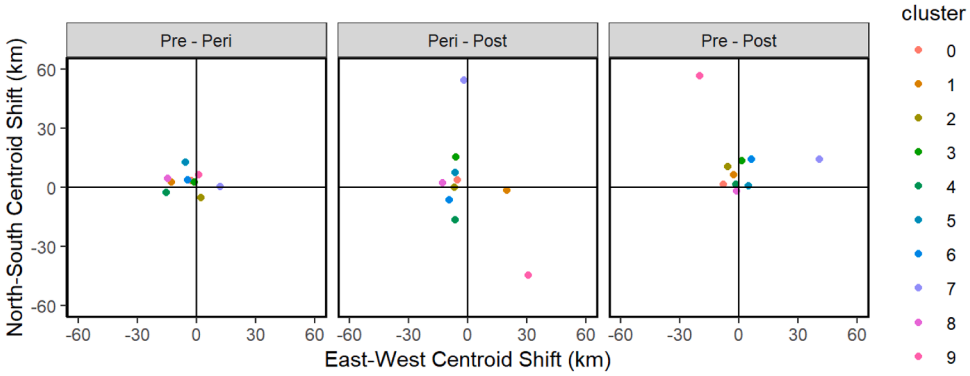
Appendix

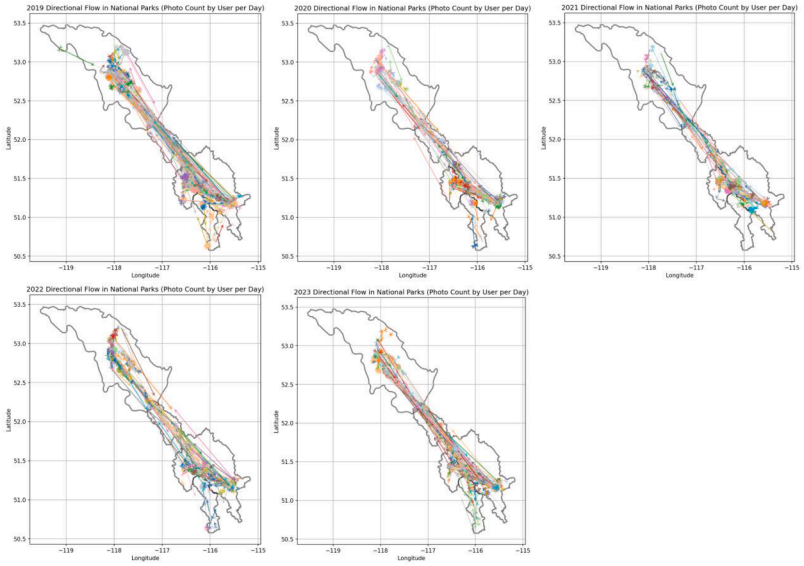
Appendix A: Hierarchical clustering of Flickr images in four national parks



Appendix B: Spatial shift of 10 clusters within national parks



Appendix C: Visitor movement within four national parks from 2019 - 2023



Data availability

Data will be made available on request.

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