Current Issues in Tourism

ISSN: 1368-3500 (Print) 1747-7603 (Online) Journal homepage: https://www.tandfonline.com/loi/rcit20

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To cite this article: Carolina Barros, Borja Moya-Gómez & Javier Gutiérrez (2019): Using geotagged photographs and GPS tracks from social networks to analyse visitor behaviour in national parks, Current Issues in Tourism, DOI: 10.1080/13683500.2019.1619674

To link to this article: https://doi.org/10.1080/13683500.2019.1619674

Published online: 21 May 2019.

CURRENT ISSUES IN TOURISM
https://doi.org/10.1080/13683500.2019.1619674

Using geotagged photographs and GPS tracks from social networks to analyse visitor behaviour in national parks

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ABSTRACT
This article explores the potential of geotagged data from social networks to analyse visitors' behaviour in national parks, taking the Teide National Park as a study area. Given its unique landscape and characteristics, plus the fact that it is the most visited national park in Spain, Teide National Park presents itself as a suitable candidate to explore new sources of data for studying visitors' behaviour in national parks. Through data from a social photo-sharing website (Flickr) and GPS tracks from a web platform (Wikiloc), we outline several visitors' characteristics such as the spatial distribution of visitors, the points of interest with the most visits, itinerary network, temporal distribution and visitors' country of origin. Additionally, we propose a practical use of geotagged data for determining optimal locations for new facilities such as information stands. Results show that data from social networks is suitable to analyse visitor behaviour in protected areas.

ARTICLE HISTORY
Received 26 October 2018
Accepted 12 May 2019

KEYWORDS
Social media data; geotagged photographs; GPS tracks; nature-based tourism; national parks; visitors' behaviour

Introduction

'Nature-based tourism' refers to all types of activities revolving around observation and appreciation of nature, as well as traditional cultures (Amo, López, & Martín, 2006; Buckley, 2008). People are increasingly moving towards an urban lifestyle and the services and facilities that come with it, leading to a near-complete disconnection from nature. Consequently activities and places that allow direct contact with 'mother nature' have become an attractive option for tourists worldwide (Newsome, Moore, & Dowling, 2012). Nature-based tourism is also considered to be a cultural ecosystem service since it provides nonmaterial benefits such as aesthetic inspiration, cultural identity, a sense of home, and spiritual experience related to the natural environment (Paracchini et al., 2014). Cultural services are ecosystems' contribution to well-being through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences (Fish, Church, & Winter, 2016).

Protected areas and particularly National Parks have become the leading destination for nature-based tourists (Balmford et al., 2009). In this regard, information that allows characterizing and quantifying nature-based tourism in protected areas is fundamental for managers and planners to devise many tasks such as budgeting, scheduling, facilities allocation, demand estimation, tourism impact assessment, and conservation and tourism management policies' design (Cessford & Muhar, 2003; Eagles, Mccool, & Haynes, 2002).

The advent of new information technologies such as the web 2.0, social networks, smartphones, and GPS, among others, and their incorporation into our daily life has revolutionized how we create, store, share and interact with geographic information. Particularly in the field of tourism, this

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phenomenon has transformed how tourists organize and share their travel experiences and have triggered the production of massive amounts of geotagged data (such as photographs, reviews, hotel reservations, check-ins notifications and GPS routes.). Data from social networks due to its high spatial and temporal resolution is useful for nature-based tourism research. It contributes to new insights about visitors' behaviour, preferences and movement, and enriches traditional data from surveys and official statistics quickly and inexpensively (Campelo & Nogueira Mendes, 2016; Lee & Tsou, 2018; Orsi & Geneletti, 2013; Sessions, Wood, Rabotyagov, & Fisher, 2016; Sonter, Watson, Wood, & Ricketts, 2016; Tenkanen et al., 2017; Walden-Schreiner, Leung, & Tateosian, 2018; Wood, Guerry, Silver, & Lacayo, 2013).

The enormous potential of data from social networks has led to a growing interest in using these data sources to study nature-based tourism (see Backgroung section). However, there is a need to further research on the applicability and effectiveness of social media data for visitor behaviour and monitoring (Heikinheimo et al., 2017). Therefore, this study is an early effort to test the feasibility of this data for visitor demand modelling. Taking Teide National Park as a case study, the main aim of this paper is to analyse visitors' behaviour using geotagged photographs from photo-sharing site Flickr and GPS tracks from web platform Wikiloc. This research explores data from geotagged photographs and GPS tracks to infer some visitor characteristics such as their country of origin, their spatial and temporal distribution and the itineraries they follow. When possible, we compare our social network data with actual park statistics in order to evaluate their coherence. The rationale is that if in some variables we obtain satisfactory adjustments, other variables for which official data are not available could also be reliable. Additionally, we propose to use geotagged data from Flickr to recommend optimal locations for information stands through the application of a location-allocation model.

Background

The main destinations for nature-based tourism are usually natural protected areas because their protected status guarantees an unaffected and natural site (Balmford et al., 2009). They enjoy exceptional natural qualities such as unique landscapes and wildlife. In this sense, national parks which maintain a special status, while also intended for visits, are the main attractions for this kind of tourism (Newsome et al., 2012). National parks are considered a symbol of national pride (Dudley, 2008). They help prevent loss of biodiversity, preserve the naturalness and magnificence of outstanding landscapes and the supply of ecosystem services such as recreation (Schägner, Brander, Maes, Paracchini, & Hartje, 2016). Moreover, visits to national parks are also a source of income for the local economies that surround them (Eagles et al., 2002).

Increasing tourist use of national parks is generally accompanied by growing pressure on resources, with both positive and negative impacts rising. Positive impacts of tourism activities are usually economic and social and include: raised awareness on conservation and preservation of natural areas (Ballantyne, Packer, & Falk, 2011), increased employment opportunities and income for local economies (Zambrano, Broadbent, & Durham, 2010) and stronger community values (Scheyvens, 1999). On the other hand, negative impacts tend to be related to ecosystem degradation. For example, higher visitation rates can lead to increases in waste produced within the natural park area and installations (Eagles & Mccool, 2002; Valentine, 1992). Also, more visitors mean higher noise levels which distress wildlife and disrupts their behaviour and natural cycles (Buultjens, Ratnayake, Gnanapala, & Aslam, 2005). Visitors activities can also lead to soil erosion and flora destruction, thus affecting the ecosystem services they provide such as soil regulation (Farrell & Marion, 2001). Therefore, it is of paramount importance for park management to have consistent, reliable and high-quality information about visitors use to provide sustainable management of national parks. In this regard, tourism geography research about visitors' behaviour can provide insights and understanding of the relationship between visitors and protected sites.

So far, most studies on tourism in national parks have focused on estimating carrying capacity (Manning, 2002), environmental impact assessment (Deng, Qiang, Walker, & Zhang, 2003; Fortin & Gagnon, 1999), visitors' impact on wildlife (Amo et al., 2006), trail design and management (Tomczyk, 2011) and methods of public participation (Brown & Weber, 2011). Nevertheless, some aspects have been researched in much less depth, such as visitor behaviour (Eagles, 2014). Visitor behaviour research is often limited by data availability and detail. Studies on this have depended on survey data and visitor estimates provided by park management agencies or official statistics. In most cases, this data lacks detail and is mostly restricted to visitor counts (Schägner et al., 2016). Data on visitors' activities, presence and schedule, are essential for park managers. Consequently, the need has arisen for alternative data sources that offer a deeper look at visitors' behaviour.

Most recently, researchers have been using tracking technologies such as GPS to collect spatial data of visitors' movement inside protected areas. GPS tracks have been proven useful to characterize visitors' intraflows (Meijles, de Bakker, Groote, & Barske, 2014; Orellana, Bregt, Ligtenberg, & Wachowicz, 2012), categorize visitors according movement patterns (Kidd et al., 2018), measure the spatial distribution of visitors' use of protected areas (Hallo et al., 2012; Taczanowska et al., 2014), evaluate the impact of informal trails (Wimpey & Marion, 2011), mapping recreational suitability (Beeco, Hallo, & Brownlee, 2014) and vehicle stopping behaviour using GPS (Newton, Newman, Taff, D'Antonio, & Monz, 2017). Although GPS data offers advantages over traditional methods such as providing more accurate and reliable data and greater spatial and temporal resolution, the use of this data implicates some problems related to: difficulties in distributing and collecting the tracking devices during experiments, higher costs derived from device acquisition and experiment design (D 'D 'Antonio et al., 2010).

New big data sources provide natural parks with original data on visitor behaviour. Big data refers to large datasets that are characterized by their volume, variety, and velocity (Gandomi & Haider, 2015). There are multiple sources of big data such as internet clicks, mobile phone calls, user-generated content, as well as purposefully generated content through sensor networks or business transactions such as sales queries and purchase transactions (George, Haas, & Pentland, 2014). Data from social networks is an attractive alternative to traditional and GPS devices for visitors' behaviour research due to its easy availability regarding cost and access. Indeed, data from social networks is a cost-free by-product of digital interactions from their users. Social networks provide a digital footprint of their users that come in a variety of formats (photographs, texts, audio, and video) and most of them are geotagged which means that data includes the location of where it was created. In this context, geotagged big data allows the spatial and temporal dimensions of social network users' behaviour to be analysed.

Mostly geotagged photographs from photo-sharing services such as Flickr and Instagram have been used to research the tourist use of natural spaces. Geotagged photographs datasets such as Flickr are a suitable approximation of visitors' annual and monthly rates (Sessions et al., 2016; Sonter et al., 2016; Wood et al., 2013). GIS modelling has also been applied to geotagged photographs to map and identify visitor flows (Lee & Tsou, 2018; Orsi & Geneletti, 2013) and to model spatial patterns of visitor use and identify factors contributing to distribution patterns (Tenkanen et al., 2017; Walden-Schreiner et al., 2018). As well, GPS tracks from route-sharing websites like Wikiloc have been used to spatialize and measure the intensity of use for mountain biking (Campelo & Nogueira Mendes, 2016). A comparative study of the information available from three popular volunteer-based geographic information platforms for walking and running in natural parks was carried out by (Norman & Pickering, 2017).

Study area

The Teide National Park (Figure 1) is located on the island of Tenerife in the Canary Islands, Spain. The island has 894,000 inhabitants and receives 5.7 million tourists a year (2017). Most of them are international tourists (78.7%), mainly from the United Kingdom (36.2%) and Germany (11%) (Cabildo

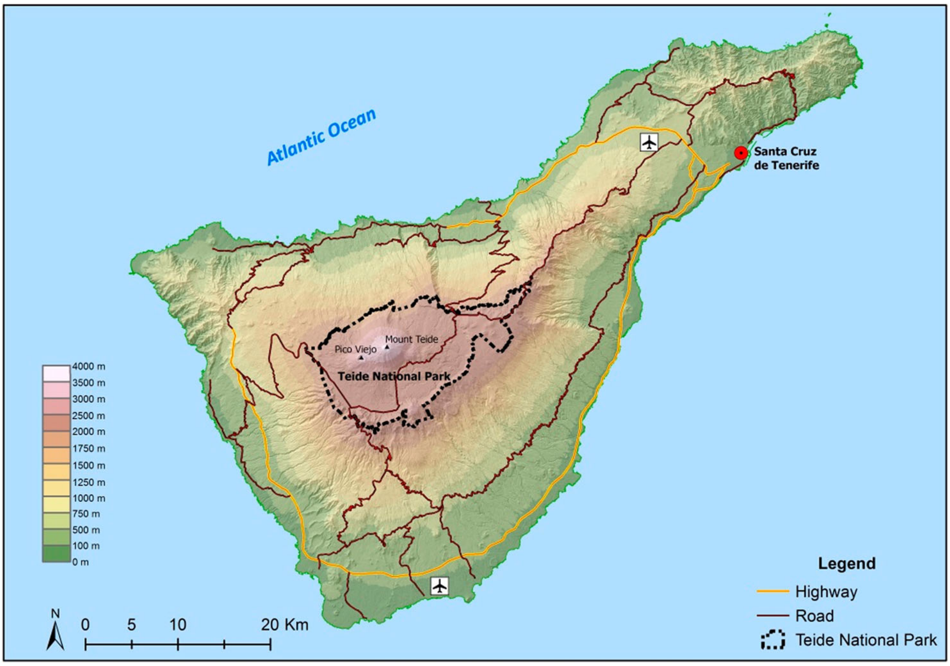

Figure 1. Location map of the Teide National Park.

Insular de Tenerife, 2018). Tourist flow to the island remains very stable throughout the year. Most tourists are attracted by the excellent weather of the Canary Islands (sun and beach tourism), but many of them take advantage of their stay to visit the main attractions of the island, such as its historic cities and Teide National Park. Consequently, pressure from tourism on the island is very high.

The Teide National Park, established in 1954, covers a surface area of 18,990 hectares which makes it the largest national park in the Canary Islands. It was declared a UNESCO World Heritage Site in 2007 in recognition of the aesthetic and geomorphologic value of 'Las Cañadas' escarpment and the Mount Teide – Pico Viejo stratovolcano. Standing 3718 m above sea level, the Mount Teide volcano is the highest peak on Spanish soil, and it stands 7500 m above the ocean floor, making it the world's third tallest volcanic structure. The park is crossed by a road that links the four access points to the park thus allowing most tourists in Tenerife to cross the park territory. There are no tolls to access the park. A well-maintained trail network, 162 kilometres long, with many infrastructures, including a cable car that takes visitors to Rambleta station at 3555 m and just 163 m from Mount Teide summit, 2 visitors' centres, 27 viewpoints, a botanical garden, and parking spaces allow its many visitors to explore the park every year (Hernández Álvarez, 2017). Visitors presence is regular throughout the year (Dóniz Páez, 2010). According to the Spanish Autonomous Organization of National Parks (OAPN), the Teide National Park is the most visited in Spain. In 2016, the park received 4,079,823 visitors (MAPAMA & OAPN, 2017).

Data and methods

Data acquisition

Official visitor data

We gathered the official visitor data about yearly and monthly visitors' estimations from the OAPN website. Official visitors' estimates are derived from vehicle counters and classifiers placed on the four access points of the park.

Visitor data estimations were available for the period 2010–2016 and show visitor numbers for year and month. Data about hourly and weekly visitor distributions was not available. Information on the country of origin was only available for the year 2016. Additionally, we downloaded GIS data of the park trail network, infrastructure and park boundaries from the OAPN website.

Flickr data

Set up in 2004, Flickr is a social website for sharing photographs and videos online. By 2016, Flickr had a community of 112 million users that uploaded an average of 1 million photos per day (The Internet Archive, 2016). In 2006, Flickr introduced the option of locating the photos uploaded on its site. Photograph geolocation can be done using the GPS on mobile devices and cameras or by selecting the location on a world map when uploading the photos from a computer (Flickr, 2017).

Data used in this research was downloaded from the Flickr public API (application programming interface) using a Python script. In total, there were 12,949 records concerning photos from 1567 users taken and uploaded throughout Teide National Park from 2010 to 2016. The data was stored in a geojson file which included the coordinates of photographs, the user ID, the time and date that the photograph was taken and uploaded and the home location of the user. We used the coordinates to create a point layer using GIS software (ArcGIS 10.3 and QGIS 2.14).

Wikiloc data

Wikiloc is a web application, also known as a map mashup that allows free GPS tracks and waypoints from around the world to be uploaded and downloaded. It was launched in 2006 and it includes a website and mobile apps for Android and iPhone. At the moment, Wikiloc had 3.3 million members and more than 7.6 million tracks which are mainly intended for hiking and cycling (Wikiloc, 2017).

Tracks crossing Teide National Park were downloaded from the Wikiloc website one by one on January 2018. The address search function was used to recover all routes that mentioned Teide National Park in their title. As a result, we found and downloaded 5064 tracks correspondent to 1078 users from 2006 to 2018. Tracks are recorded in gpx files which consist of GPS points taken by the user along the route. ArcGIS was used to convert the waypoints into point layers and then into lines by using the tracking analyst tools.

Pre-processing

Spatial aggregation

Data collected from Flickr accurately identify where a specific user took every photograph within the boundaries of the Teide National Park. As this study focuses on visitors' analysis, it was important to account for Flickr users instead of photographs to exclude the bias produced by single users taking several pictures at the same location. Therefore, geotagged photographs were aggregated in hexagons, and the number of users and photographs were counted for each hexagon. Based on the method proposed by (Lee, Kwon, Yu, & Park, 2016), we determined 200 meter-sided hexagons as the optimal size to aggregate our data according to the scale of our study area. The method uses Moran index to evaluate which size hexagon size has the highest autocorrelation according to different zoom levels. Under this approach, the aggregated data maintains the statistical properties of the point data and minimizes the modifiable-areal-unit-problem (MAUP) effect. We calculated Moran index for 100, 200, 300 and 400 meter-sided hexagons and 200 m sided hexagons yielded the highest value for spatial autocorrelation. Similar studies have also applied this approach to analyse data at the user level (García-Palomares, Gutiérrez-Puebla, & Mínguez, 2015).

Map matching

GPS Tracks downloaded from Wikiloc may not perfectly match the digital road and trail network within the park due to GPS location errors. In order to assess visitor' use of the trail network (number of visitors walking along each section of the network), the GPS tracks should be adjusted to the digital trail

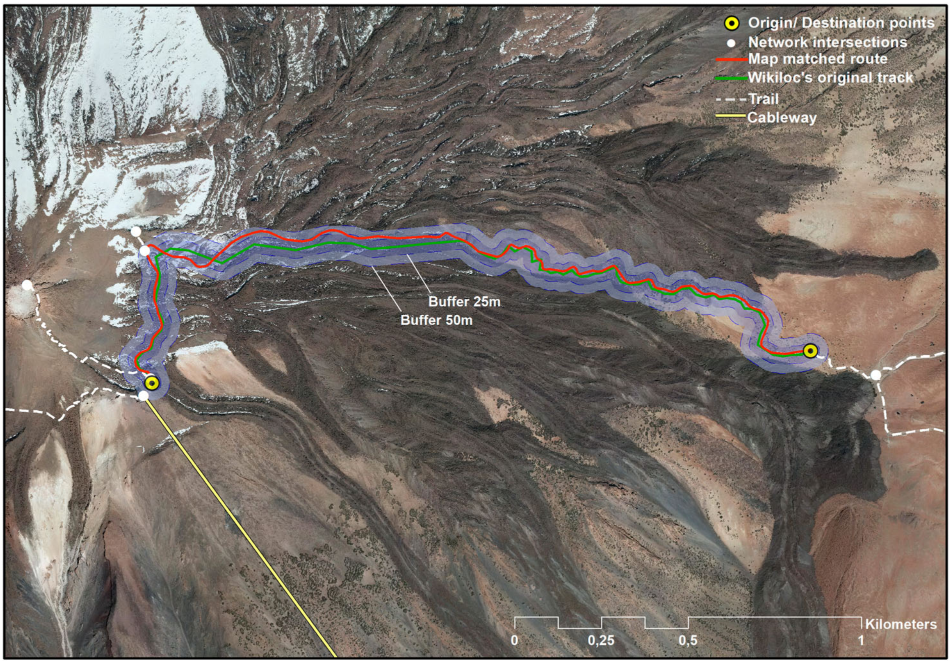

Figure 2. Illustration of the Map-matching process. Route map-matched within the 50 m distance buffer. A buffer distance of 25 m would prevent the matching of this route.

network by a process known as map matching. We applied a map matching tool based on the algorithm developed by Dalumpines and Scott (2011). The procedure creates a buffer around the GPS trackline that constrains the estimation of the shortest path between the origin and the destination, by using Dijkstra's algorithm. In this process, the definition of the buffer distances determines the results: a buffer too small may prevent the matching of many routes, while a buffer too wide may lead to inaccurate or incorrect routes (Figure 2). The GIS-based tool uses route analysis tools from the network analyst extension of ArcGIS to generate the shortest path between the track's origin and destination along the digital network. The resulting route is the adjusted GPS track (Romanillos & Gutiérrez, 2019). The Map matching tool was also used to adjust itineraries routes created from Flickr sequence of geotagged photographs belonging to one user on the same day.

Analysis

Home location attribute extraction

The home location attribute provided by Flickr users on their account profile was used to infer the country of origin for visitors to the park. Out of the 12,949 photographs, 52% of users had registered their home country. This proportion matches results from other studies that analysed the origin of visitors using Flickr data (Wood et al., 2013). A semi-automated method was applied to classify the origin of every user in our dataset. First, the number of users was summarized according to the home location attribute. Then, irregularities presented by misspelling or abbreviated country names were rectified. Results were compared with official survey data from 2016 by correlation analysis. For this part of the study, we only used the Flickr data from 2016.

Temporal aggregation

Geotagged photographs provide a source of time data which helps to identify temporal patterns for visitors. We used the timestamp on which each photograph of the dataset was taken to outline visitor flow and monthly, weekly and daily distribution of visits. The time series of the data collected goes from January 2010 to December 2016. From data collected, we determined the total number of unique users per day. These values were summed monthly for every year and yearly. From these values, we calculated average users for each month and compared them with the average monthly visitors. To test the strength of the linear relation between monthly users and official data of monthly visitors, we obtained the Pearson's correlation coefficient considering the 2010–2016 period for both data sources. Similar approaches had been applied to use temporal data on geotagged photographs from Flickr (Tenkanen et al., 2017). Additionally, we obtained the weekly and hourly distribution of users.

Spatial autocorrelation

One of the most exciting features that geotagged data shows is the possibility to visualize the location of visitors during their visit. This 'spatial component' allows exploring spatial patterns of visitors' distribution within the park through Exploratory Spatial Data Analysis (ESDA). ESDA comprises a set of methods to describe and visualize spatial distributions which focus on distinguishing characteristics of geographical data and, specifically, on spatial autocorrelation and spatial heterogeneity (Anselin, 1995). We used Global and Local Moran Indexes on aggregated Flickr user data to find where people go within the park, which places attract a significant concentration of people and which places are neglected.

Anselin's LISA (local indicator of spatial association) Index (Anselin, 1995) was calculated in order to detect the location and extent of spatial clusters of high and low values and outliers. This index identifies four types of clusters: HH (statistically significant cluster of high values), LL (statistically significant cluster of low values), HL (an outlier in which a high value is surrounded by low values), and LH (an outlier in which a low value is surrounded by high values). We used the fixed distance band method with a threshold distance of 1500 m for LISA analysis of Flickr users. We selected this value after applying different thresholds in order to obtain the maximum spatial autocorrelation value. The results obtained using the fixed distance band method and the inverse distance method were quite similar. However, the LISA map obtained using the fixed distance band of 1500 m yielded a better result including more significantly clusters and outliers than the inverse distance method.

Itinerary mapping

Each geotagged photograph from Flickr represents a spatial–temporal event defined by a user's location at a specific time. When several of these events belong to the same user, it is possible to track his/her travel path by connecting the time-ordered event locations in space, hence obtaining an itinerary for every visitor of the park that has uploaded several photographs within the same day. In this way, we intended to approximate the itineraries followed by the majority of visitors to the Teide National Park road and trail network. For this, we selected every Flickr user that have uploaded more than 10 photographs in a single day.

Tracking analyst tools produced an itinerary network of users that have uploaded more than 10 photographs in a single day. A total of 290 users met this condition. The resulting network was then adjusted to the trail network by using the map-matching tool. Subsequently, route density was estimated by counting the frequency of tracks on each trail of the park network.

A succession of photographs taken by the same user on the same day demonstrates the paths that tourists follow when sightseeing. However, some visitors are particularly interested in recreational activities (hiking, mountain biking) and their behavioural patterns differ from most tourists. This type of park use can be captured using the GPS tracks voluntarily uploaded in dedicated sports web services. Using the previously adjusted tracks from Wikiloc, an overlay analysis was performed to estimate the tracks' density on the Teide National Park trail network.

Optimal location of information stands

As an example to show the practical use of new data sources for park managers, we apply a model in order to calculate the optimal location of information stands. Once the need for information stands has been determined by a visitor or employee survey, we propose to use Flickr users' spatial distribution as a proxy of the spatial distribution of potential demand for information kiosks. The rationale of this application is that the higher number of visitors next to the kiosks, the higher the probability that they will be used by visitors.

We used ArcGIS network analyst module to model potential demand from geotagged photographs and apply a location-allocation model to find optimal locations for information stands. Out of the six solutions proposed in ArcGIS, we opted for the maximize attendance approach. This solution aims to maximize the attendance of demand that the facility can cover within a specified distance (Holmes, Williams, & Brown, 1972). In this model, the facilities are chosen to allocate as much demand weight as possible while assuming the demand weight decreases about the distance between the facility and the demand point (ESRI, 2018).

The location-allocation models require three main inputs; a road network, a set of candidate facilities and the demand points (Mitchell, 2012). We build a network layer from the road and trail layers provided by OAPN. 557 candidate locations were considered for establishing the information stands. These are located along the main road that crosses the park at a fixed interval of 100 metres because the road connects the four access points to the park and it is the starting point for the majority of the trails so all visitors must travel this road. Visitors' potential demand was modelled from the Flickr users count on the hexagon grid and then transformed into a point layer. Each demand point depicted the number of users within a single hexagon. As well, two required facilities that correspond to the two visitor's centres were considered in the model.

Four scenarios based on the number of additional facilities beside the two existing ones were considered; 1, 3, 5 and 10. We also established four cut-off distances; 1000, 1500, 2000 and 2500 m to perform a sensitivity analysis and find out what is the maximum demand coverage for each chosen facility and the existing visitor centres.

Results

Social media geotagged data visualization

Figure 3 shows the distribution of the 12.949 geotagged photographs along the Teide National Park from 2010 to 2016. Overall, users took a median of two photographs. The highest active user uploaded a total of 419 photographs. Photographs distribution varied across the years. Year 2016 reported the maximum number of photos (2646) and year 2010 had the lowest number of photographs (618).

Photograph locations are well aligned with the location and shape of the main road and trail network of the park. High density along this road suggests people are taking photographs either from vehicles or at the viewpoints located adjacent to the road. As expected, most Flickr photos concentrate on the main points of interest within the park. For instance, we observe a significant concentration of photos in four places; Mount Teide summit (1), the cableway base station (3) Cañada Blanca visitors' centre (4) and Roque García viewpoint (5).

Figure 4 displays the 5064 GPS tracks collected by 1760 users from the Wikiloc site. Users recorded a median of two tracks. The user with the highest number of tracks uploaded 55 routes. The tracks display five activities; hiking, climbing, running, cycling and motorcycling. Hiking is the most popular activity with 77% of the tracks, followed by running 8%, cycling 8%, climbing 7% and, motorcycling 1%. Tracks' length goes from 0.3 Km to 44Km. The majority of tracks fall within the trail and road network of the Teide National Park. However, there are tracks which are located outside official trails that could indicate the creation of new trails by the visitors.

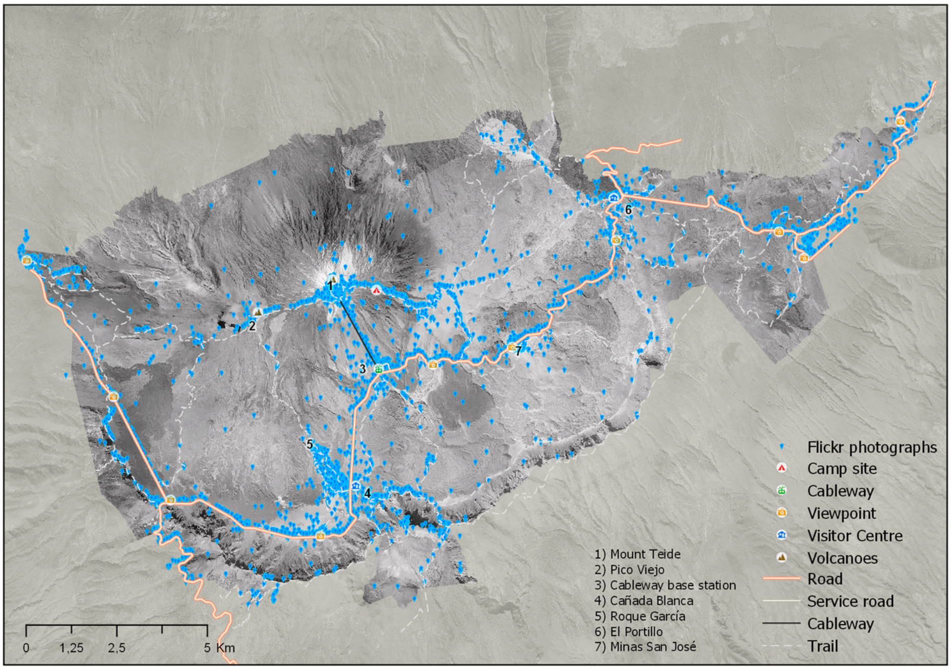

Figure 3. Spatial distribution of Flickr photographs 2010–2017.

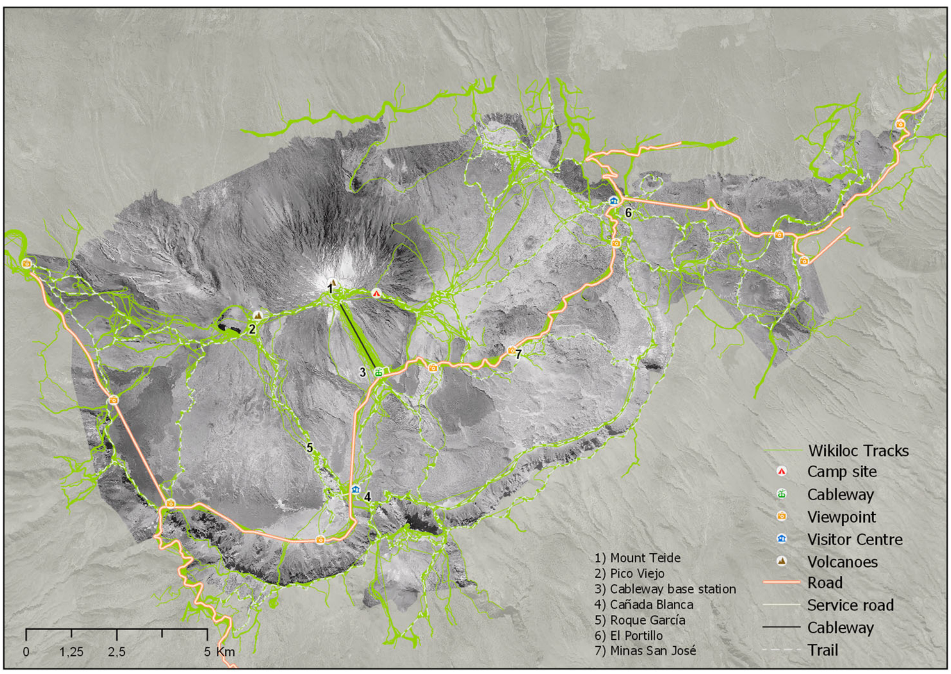

Figure 4. Location of Wikiloc Tracks 2006–2018.

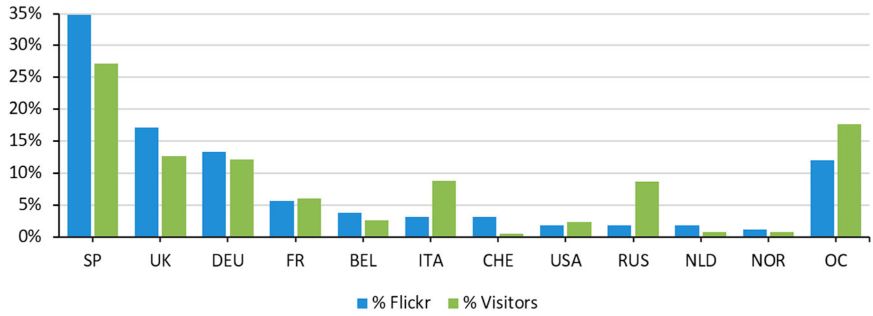

Figure 5. Origin of visitors according to Flickr and Visitor survey; SP: Spain, UK: United Kingdom, DEU: Germany, FR: France, BEL: Belgium,, ITA: Italy, CHE: Switzerland, USA: the United States, RUS: Russia,, NLD: Netherlands, NOR: Norway, OC: other countries.

Country of origin

The home location attribute from Flickr shows that visitors come from 27 countries. Comparison between 2016 Flickr users and survey data from the same year (OAPN, 2017) resulted in a strong positive correlation ($r = 0{,}88$, $p = 0.001$). The majority of visitors are international (69%) whereas national visitors account for 31%. As expected most of the international visitors come from European countries, mainly from the United Kingdom (26%), Germany (24%) and France (7%) (Figure 5). Overall, international visitors posted an average of 9 pictures whereas national visitors posted 7 pictures.

This data on country of origin is useful for parks managers in order to provide information to the visitors. Since most foreign visitors come from the United Kingdom and Germany, the information kiosks proposed in our study should offer information in at least Spanish, English and German.

Temporal patterns

Figure 6 shows the average monthly distribution of users from 2010 to 2016 along with the average monthly distribution of visitors from survey data. The Teide National Park has regular affluence during the year, with slight peaks in March and August which coincide with the Easter holidays and summer seasons respectively. Flickr users' monthly data for the same period is well aligned with official visitor data provided by OAPN. We found a high correlation value between both estimates ($r = 0.84$, significant at the 0.001 level).

As well, Flickr data show that the flow of visitors is constant throughout the week, with a slight rise at the weekend, related to a greater presence of inhabitants from the island who visit the park for recreational activities (Figure 7).

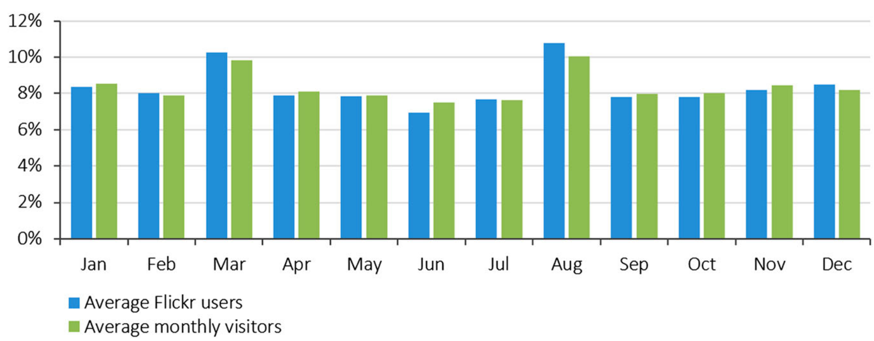

Figure 6. Average Monthly distribution of Flickr users and Teide National Park visitors (2010–2016).

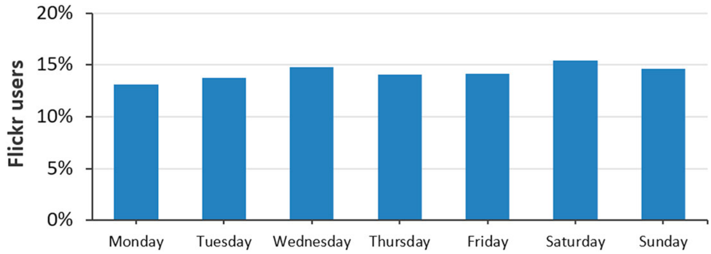

Figure 7. Distribution of Flickr according to days of the week.

More interesting are the hourly distribution data from Flickr users (Figure 8). There is a very high concentration of visitors in the central hours of the day, particularly between 11 am and 5 pm. The high temporal and spatial concentration of visitors (see the following subsection) suggests that overcrowding problems occur at certain times and in certain places and the carrying capacity of some places within the park could be exceeded. Since the presence of visitors is much lower outside the central hours of the day, park managers could mitigate overcrowding with actions aimed at redistributing the flow of visitors throughout the day.

On a more detailed level, we differentiated the hourly distribution of visitors according to the places that gathered the majority of users; Cañada Blanca visitor' centre (270 users), Roque García (429 users), Mount Teide summit viewpoints (287 users) and the cableway base station (175 users). As a result, (Figure 8), these distributions outlined the daily visitor patterns of each attraction thus allowing us to identify at which time these places are more or less crowded. For example, the Cableway base station' distribution indicates a higher concentration of visitors from 10:00 to 12:00 which account for the 42% of the entire daily visitors. The same can be said for Mount Teide viewpoints where the majority of visitors converge from 11:00 to 14:00 thus accounting for 55% of visitors. In contrast, Cañada Blanca visitor centre and Roque García viewpoint show a more evenly distribution of visitors throughout the day.

Spatial patterns

The Moran's global index yielded a value of 0.389 (p-value = 0.00000) which shows a positive spatial autocorrelation, thus following a pattern of spatial clustering. The scatter plot reflects

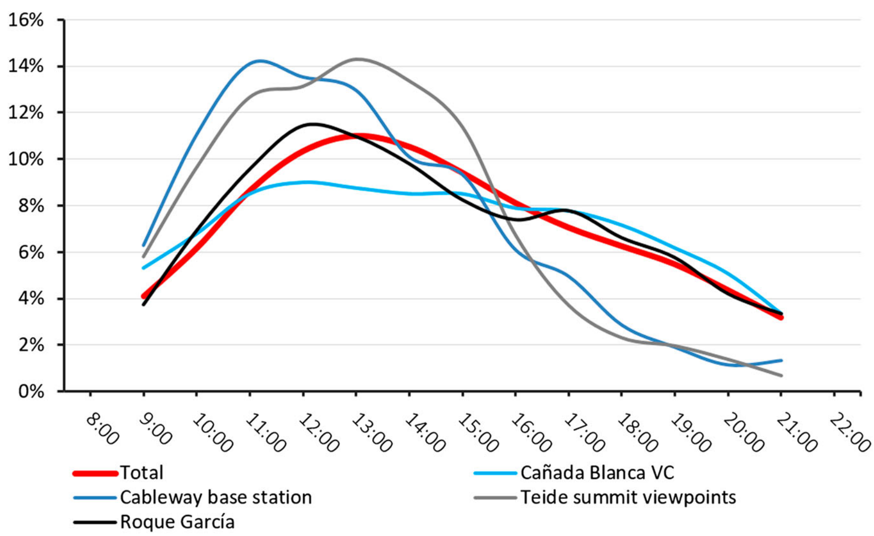

Figure 8. Hourly distribution of total visitors and in main park attractions.

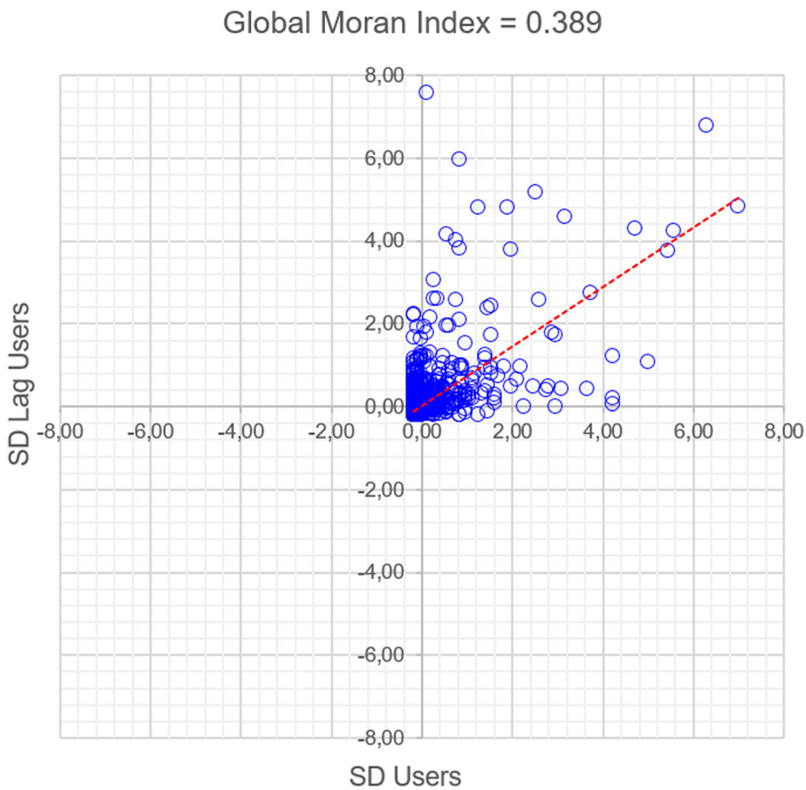

Figure 9. The Moran's I scatterplot of Flickr's users in the Teide.

the asymmetry of both distributions (Figure 9). Figure 10 shows the spatial distribution of the clusters: H-H values match areas of high tourist concentration in places where there are paths on which visitors can walk so that they form high-value clusters: Five high-high clusters can be identified: Mount Teide summit, 'Cañada Blanca' visitors' centre, Altavista mountain refuge, Roque García viewpoint, Ucanca Plain viewpoint. H-L values correspond to confined hot spots from which there are no walking opportunities. They are either parking lots or transference stations such as the cableway base station, not connected to trails, from which visitors take photographs. Therefore, they are outliers, points of high concentration of visitors surrounded by 'empty' points. Table 1 summarizes the main results of every cluster.

Itinerary mapping

Itineraries identified through the sequence of geotagged photographs by the same user in a single day follow a clear pattern across the main road that crosses the Teide National Park and the cableway line (Figure 11). The results suggest that the majority of photographs are taken from vehicles and viewpoints located along the road, as well from the cableway car. Flickr itineraries hardly reflect the trail network, the only exception being the trail that climbs up to the Teide summit from the south and some minor itineraries.

Wikiloc offers complimentary data that portrays a different use of the park. While Flickr tracks showed visitor flows across the main road thus depicting visitor activities such as sightseeing, Wikiloc data reflects a more active use of the park by its visitors. Figure 12 shows the tracks' density in each trail section, as an approximation for the popularity and use of trails for hiking and cycling. Particularly noteworthy is the trail to climb the Teide summit from the southeast, as well

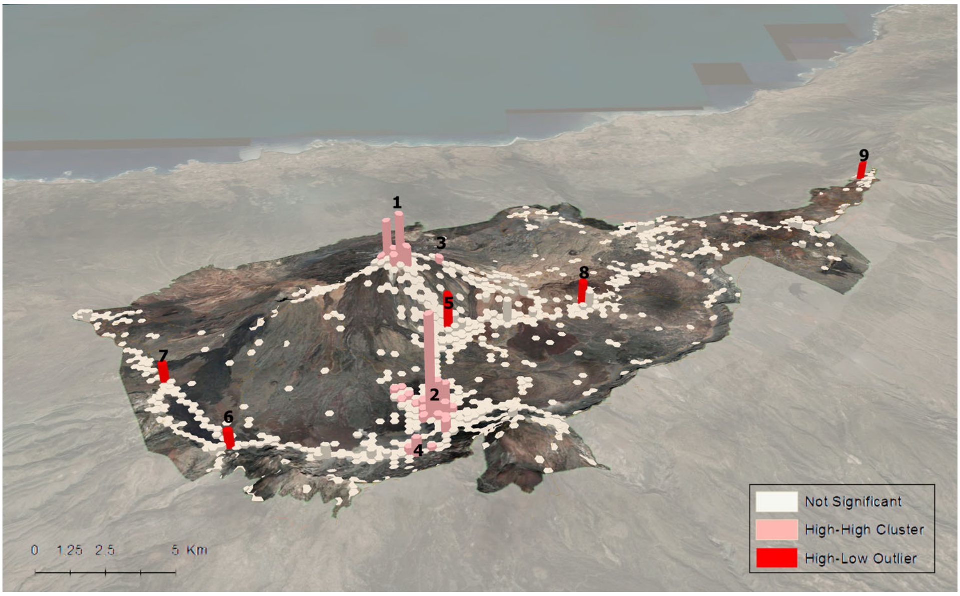

Figure 10. Anselin Local Moran's Index Map at the user level.

Table 1. Statistics of point of interest's clusters.

#	Cluster/Outlier	Name	# hexagons	Users	LM Index	*p* value
1	H-H cluster	Cañada Blanca	16	913	124.28	0.001
2	H-H cluster	Mount Teide	10	601	75.76	0.003
3	H-H cluster	Llano de Ucanca	4	106	32.69	0.009
4	H-H cluster	Roques de García	4	60	27.83	0.002
5	H-H cluster	Altavista refuge	1	22	28.32	0.000
6	H-L outlier	Cableway base station	1	114	−29.78	0.000
7	H-L outlier	Minas San Jose	1	80	−16.31	0.013
8	H-L outlier	La Tarta	1	64	−11.51	0.010
9	H-L outlier	Narices del Teide	1	61	−20.36	0.000
10	H-L outlier	Boca de Tauce	1	57	−19.42	0.002

as the trails that give access to the peak from the south (Cañada Blanca) and the northeast (Valle de la Orotava).

Optimal location of information stands

Figure 13 shows the required and chosen locations for the four scenarios proposed. The demand assigned to each facility is represented by the number of hexagons covered at each distance cut-off. In all of the scenarios, the locations for additional information stands are well distributed across the park terrain and match up with the viewpoints locations. The maximize attendance model prioritizes locations where demand points with higher weight are located closer. In the first scenario, when the model has to add just one extra facility, two different optimal locations are chosen based on the distance cut-off. For a distance cut-off of 1000 m, the optimal location for a new facility is located in the Minas San José viewpoint whereas for the three remaining distance cut-offs the chosen location is located in the cableway base station. In the rest of the scenarios, the same locations are chosen for the different distance thresholds.

The chosen location that matches the cableway base station seems to gather the most potential demand for all scenarios. Existing facilities (visitors' centres) can cover between 23% (1000 m distance) to 34% (2500 m) of the potential demand (Table 2).

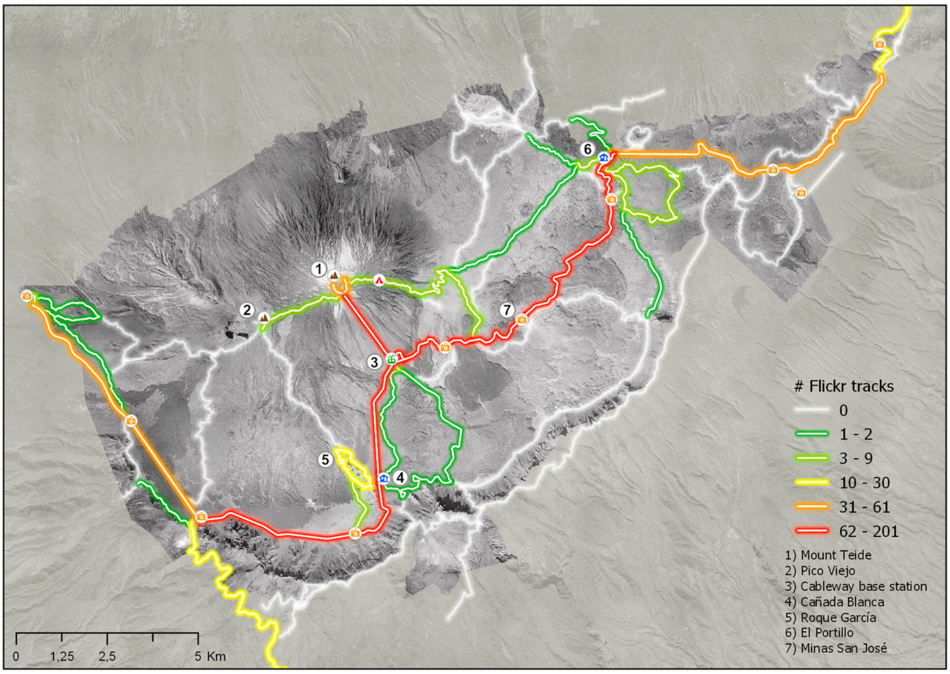

Figure 11. Route density of Flickr tracks.

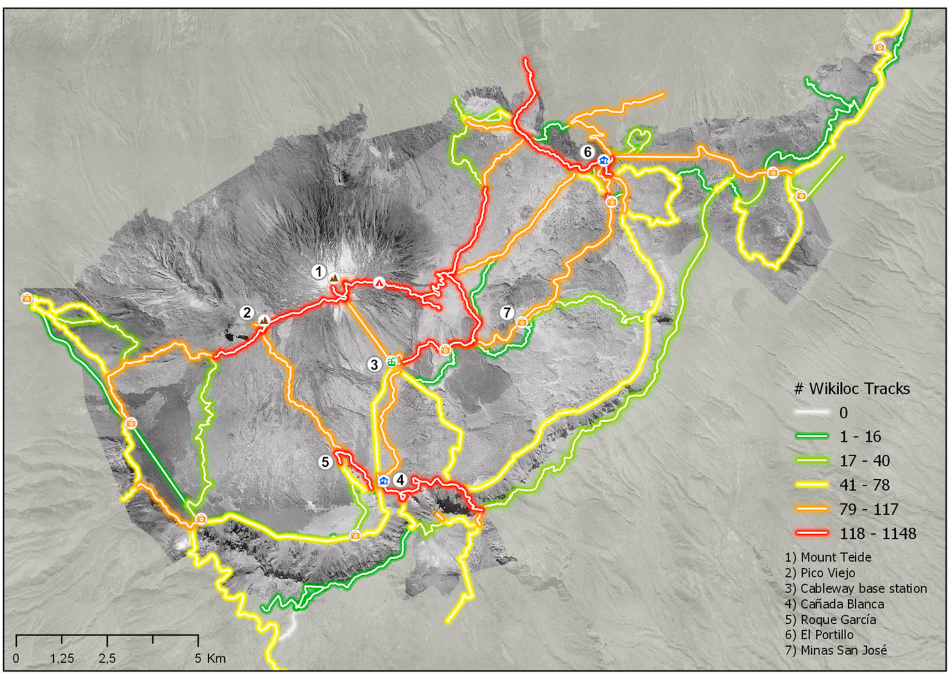

Figure 12. Route density of Wikiloc tracks.

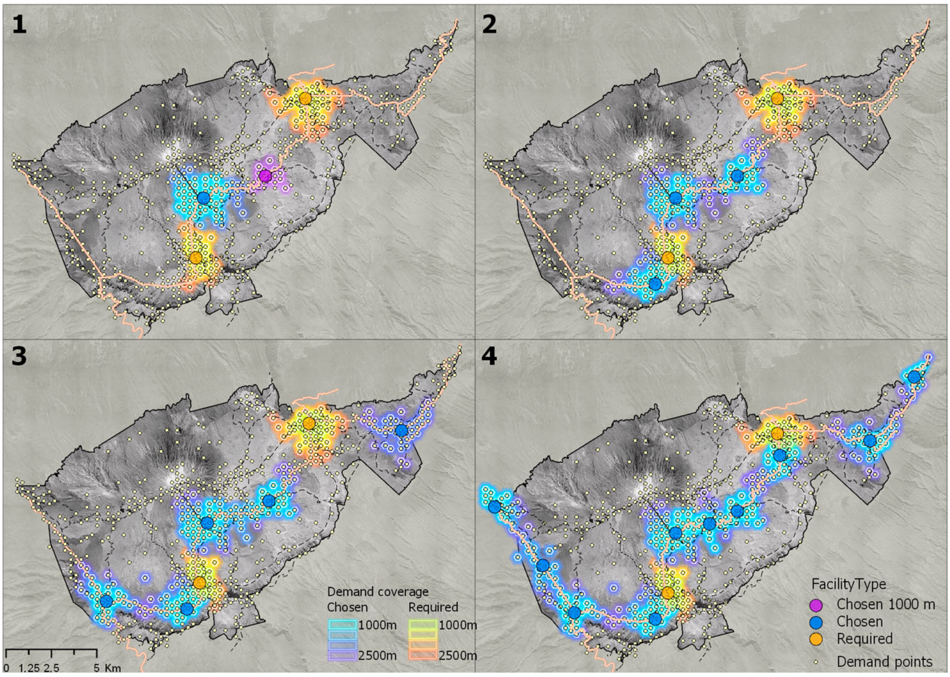

Figure 13. Results from the location-allocation models: (1) 1 additional facility, (2) 3 additional facilities, (3) 5 additional facilities, (4) 10 additional facilities.

As additional facilities are allocated, there is a significant increment in covered demand for all cut-off distances (see Table 3). Thus, for example, with the allocation of just one facility, the demand covered increases from 23% to 36% (1000 m cut-off distance). Only, when 10 facilities are added, and the distance cut-off is set to 2500 m, the demand is fully covered.

Discussion

Park managers rely on visitation data to inform policy and management decisions. However, visitation data is often costly and burdensome to obtain and provides a limited depth of information (Sessions et al., 2016). Fortunately, the growing availability of social media data opens new avenues for nature-based tourism research and management. Thus, for example, geotagged photos can provide use estimates and hot spots for large areas quickly and inexpensively (Walden-Schreiner et al., 2018). In our study, geotagged photographs from Flickr and GPS tracks from Wikiloc provided a close approximation to visitor behaviour in the Teide National Park thus allowing several characteristics of its tourist use to be outlined such as points of interest, visitor concentration and movement, country of origin and visitor distribution over time.

This work validates data from social networks using official data when they are available. The rationale is that if in some variables we obtain satisfactory adjustments, other variables for which

Table 2. Covered demand for 2 existing facilities.

Cut-off Distance	Average distance (m)	Demand	Weighted demand sum	% covered demand by existing facilities
1000 m	616.63	372	314.83	23
1500 m	937.37	454	405.17	29
2000 m	1146.70	494	491.52	31
2500 m	1306.54	538	559.06	34

Table 3. Covered demand for chosen facilities in all scenarios.

Scenarios	Cut-off Distance	Average distance (m)	Demand	Weighted demand sum	% covered demand by new facilities	%Total demand covered (existing + new facilities)
1 facility	1000	560.89	200	192.44	13	36
	1500	943.55	337	262.31	22	51
	2000	1152.86	404	334.64	26	57
	2500	1377.41	444	391.52	28	62
3 facilities	1000	580.20	493	507.11	31	54
	1500	866.87	580	636.16	37	66
	2000	1070.64	639	749.63	41	72
	2500	1280.18	699	854.41	45	79
5 facilities	1000	575.94	630	731.19	40	63
	1500	841.86	707	902.7	45	74
	2000	1080.68	799	1049.41	51	82
	2500	1307.86	878	1210.26	56	90
10 facilities	1000	561.27	840	1161.05	54%	77%
	1500	820.26	912	1425.04	58%	87%
	2000	1006.03	953	1645.14	61%	92%
	2500	1193.04	1038	1844.61	66%	100%

official data are not available should also be reliable. We could validate two variables: country of origin and monthly distribution of visitors. Thus, the relationship between the distribution of visitors by nationality according to Flickr data and survey data provided by the park managers exhibits a high Pearson's correlation coefficient ($r = 0.88$), where Spanish, German and British are the most represented nationalities. An exploration of the temporal distribution of Flickr users within the park revealed a continuous flow of visitors through the year which is consistent with conventional data estimated by the park with automatic counters ($r = 0.84$). These findings prove that Flickr data are highly reliable to estimate the origin of the visitors and their monthly distribution. These results are consistent with those obtained on previous research in Finland and South Africa (Tenkanen et al., 2017). They found that half of the analysed parks (28/56) had a Pearson's correlation coefficient equal to or higher than 0.7. The high correlation value obtained in Teide National Park is probably due to its high number of visitors, which provide a sufficiently large sample of Flickr users.

When validating Flickr data, we have to consider bias not only in Flickr but also in official data. Each measurement technique for counting visitors involves sampling error and biases (Sessions et al., 2016). The number of monthly visitors reported by the Teide National Park is an estimation, since it counts vehicles, not people, and apply an estimated person-per-vehicle multiplier. Also, surveys may also be biased towards particular types of visitors. Surveys might potentially under-sample international visitors (Sessions et al., 2016).

Flickr and Wikiloc provide additional information, not available in official sources, particularly on spatial patterns of visitors. The social activity of sharing pictures leaves digital proxies of spatial preferences, with people sharing specific photos considering the depicted place not only 'worth visiting' but also 'worth sharing visually (Gliozzo, Pettorelli, & Muki Haklay, 2016). The spatial patterns revealed in this study suggest that visitors to Teide National Park tend to converge at three points of interest: the summit of Mount Teide, Roque García and the Cañada Blanca visitors' centre. Data on the spatial and temporal concentration of visitors can alert park managers about crowding problems and provide useful information for decision-making to face them. The results obtained from the location-allocation models showed that Flickr might be used to locate new facilities within the park, which can be valuable for decision making and resource optimization in park management, as visitor infrastructure is a key component to attract visitors.

Data from social networks also provide information on the itineraries followed by visitors within the park. According to Flickr data, the majority of visitors follow the main road and a limited number of trails. Wikiloc data shows that visitors frequently use the majority of trails within the park. Our interpretation is that Flickr and Wikiloc provide complementary information on the use of the network of roads and trails: while Flickr mainly detects flows of visitors when sightseeing, Wikiloc identifies trails used when hiking or climbing.

Data from social networks prove to be of great value for park managers who need up-to-date information about visitors' use of the protected site in order to manage these sites properly. The growing number of tourists in national parks poses new challenges to park managers, who must efficiently manage visitor flows and avoid over-crowding and unwanted impacts. The visitors' digital footprint also helps detect the presence of tourists in particularly sensitive areas within the national parks.

Despite the high resolution of social media data in terms of time and space, there are some limitations that we need to address. First, we have to consider bias in the data sources. Social media data is biased by their popularity among users, and it may vary by country, year and demographics. Second, in less popular parks, the volume of data collected is reduced thus decreasing the significance of the analysis. In this aspect, social media data should be used with caution. Finally, there is also the bias produced by highly engaged users which can lead to an overrepresentation of such population. Analysis at the user level proved to be more accurate than at the photograph level to detect country of origin, or where visitors go within the national park and when because it removes the bias effect of highly active users thus providing a reliable indicator of tourist use.

Conclusions

This study showed how geotagged data from social networks could be used to measure different aspects of visitor behaviour. In parks where the budget for surveys and visitor monitoring studies is reduced or non-existent, geotagged data presents as an accessible and inexpensive alternative. For parks where visitor monitoring is carried out, geotagged data can be a supplementary source to assess visitation and decision making.

Data from social networks like Flickr and Wikiloc provides dynamic and high detail data which in contrast to survey data provides a continuous record of visitor behaviour. So the use of social networks can be a good alternative in parks that do not have resources to carry out surveys or to install automatic counters. In the same way, parks that carry out visitor monitoring can complement their visitor data. Most importantly, social networks provide highly accurate spatial information on visitors' behaviour thanks to the data captured by their mobile GPS devices, identifying hot spots and visitor itineraries in national parks.

Flickr can provide a reliable indicator of visitors' country of origin which is an important characteristic of visitors as it contributes to outline visitor's profile. This information is needed to develop effective communication strategies and programmes such as information about the park characteristics and activities which can enhance the visitor's experience as well as to efficiently communicate conservation and environmental values.

We presented an early application of geotagged data to model visitors' demand and find optimal locations of new information kiosks that need further development/adjust to provide more comprehensive insights. For example, a preliminary survey that addresses the use level of existing facilities could help to define the number of additional facilities. Moreover, spatial modelling of geotagged data can be used to identify optimal location of different services such as camping sites, washrooms and emergency spots or to design optimal routes for new itineraries and to maximize accessibility to least used trails.

This study is an initial step towards finding new applications for social media data in nature-based tourism research, particularly in national parks. We presented exploratory data and a visual analysis that outlines the main characteristics of visitor behaviour. Analysing data from social networks offers valuable and innovative information for tourism and geographic research. Insights gained during this study on visitors' spatiotemporal patterns are relevant for parks managers and can be applied in other national parks.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by Comunidad de Madrid (Madrid Regional Government) SOCIALBIGDATA-CM: [Grant Number S2015/HUM-3427].

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