Journal of Outdoor Recreation and Tourism 42 (2023) 100624

Contents lists available at ScienceDirect

Journal of Outdoor Recreation and Tourism

journal homepage: www.elsevier.com/locate/jort

Research Article

Squeezing the most from volunteered geographic information to monitor mountain biking in peri-urban protected and recreational areas at a metropolitan scale

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ARTICLE INFO

Keywords:
VGI
Mountain bikers
Peri-urban parks
Monitoring
GPS tracks

ABSTRACT

Recent studies have proved that volunteered geographic information is a valid data source to monitor outdoor activities within protected and recreational areas. However, these studies were carried out mainly at local scales, overlooking the real potential of such data for managing recreational activities on larger scales. In this research, using 9526 mountain bike tracks shared by 1319 identified riders, we studied 5 different peri-urban parks in a large metropolitan area. We learned that mountain biking actively targets these areas and that recreational behaviours shift according to each location. Users' commitment could be inferred from the dataset, adding new value to previous studies. This broader scale can also provide insights regarding riders' preferences and behaviours, providing park staff and managers with better information ranging from use intensity in the entire area to identifying environmental and social conflicts, thereby allowing measures to be taken to mitigate these.

Management implications:

- GPS tracks from volunteered geographic information (VGI) can provide park managers with information regarding recreational uses in their territories.
- Uses and behaviours vary among local protected and recreational areas (P&RAs) regarding mountain biking in a metropolitan context.
- These datasets can help managers of P&RAs to monitor mountain biking activity, its displacement and intensity. The datasets also help to identify suitable locations for implementing real counts, surveys, or awareness campaigns targeting this particular user group.

1. Introduction

Protected and recreational areas (P&RAs) are important territories worldwide. While the former are considered the main way to preserve biodiversity and conserve nature (Pickering, 2010; Worboys, Lockwood, Kothari, Feary, & Pulsford, 2015), recreational areas, in the context of globalization and urban development, are important places to reconnect with nature and the open air, especially within large metropolitan areas (Colléony, Prévot, Saint Jalme, & Clayton, 2017; Miller & Hobbs, 2002). P&RAs are also important as laboratories for sustainable development (Braun, 2020) and ideal places to retreat to from our hectic lives, offering tourism opportunities and healthy and satisfying leisure activities (Manning, 2014). They also offer several ecosystem services such as, among others, climate and water regulations, water supply, erosion control and sediment retention, soil formation, nutrient cycling, pollination, genetic resources, recreation, and cultural (Costanza et al., 1997).

The use of these territories for outdoor recreational activities is growing worldwide (Balmford et al., 2009; Boman, Fredman, Lundmark, & Ericsson, 2013; De Valck et al., 2017). Although there is a clear positive impact on human health (Triguero-Mas et al., 2015), massive use could jeopardize more sensitive parts of P&RAs, having negative effects

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https://doi.org/10.1016/j.jort.2023.100624
Received 22 January 2021; Received in revised form 21 February 2023; Accepted 26 February 2023
Available online 16 March 2023
2213-0780/

on soil (compaction, erosion, loss of organic matter, increased runoff), vegetation (trampling, loss of biomass, change in composition, introduction of exotic species) and wildlife (increased vigilance, flight, and changed spatial behaviour and patterns of activity) (Graf et al., 2018; Marion, Leung, Eagleston, & Burroughs, 2016; Pickering, 2010; Pickering, Hill, Newsome, & Leung, 2010). The use of natural outdoor areas has also changed dramatically over recent decades. From contemplative light/moderate physical activities with low levels of damage to nature such as walking and birdwatching, there was a move to highly demanding physical activities such as mountain biking, trail running, climbing and rafting, in many cases through large organized events with massive participation (Nogueira Mendes, Farías-Torbidoni, & Pereira da Silva, 2021; Perić & Slavić, 2019; Segui Urbaneja & Farías Torbidoni, 2018). Therefore, to accomplish the main mission of these areas (i.e. to preserve nature and biodiversity and to allow the regular course of ecological cycles), better knowledge is required about activities and practitioners, entailing more and better information and faster monitoring techniques.

One of the latest data sources used to monitor outdoor activities within P&RAs is Volunteered Geographic Information (VGI), as proposed by Goodchild (2007). Exploiting the potential of web-share services, sports apps and social media, and the proliferation of tablets, smartphones and smartwatches equipped with location features, several studies have tested these data sources to monitor the recreational use of P&RAs. Results demonstrated that these data sources can easily show where several different recreational activities take place (Ciesielski, Sterenczak, & Balazy, 2019; Nogueira Mendes, Silva, Grilo, Rosalino, & Pereira da Silva, 2012; Santos, Nogueira Mendes, & Vasco, 2016; Walden-Schreiner, Leung, & Tateosian, 2018), even when the amount of data is small, i.e. n = < 1000 (Norman & Pickering, 2017; Walden-Schreiner, Rossi, Barros, Pickering, & Leung, 2018). Massive use provides massive datasets (data which are often free), allowing the testing of VGI as a long time series (Nogueira Mendes & Pereira da Silva, 2018), or allowing researchers to infer how visitors value particular destinations (Pickering, Walden-Schreiner, Barros, & Rossi, 2020; Rosário et al., 2019). On-site counts were found to correlate positively with web-share services and information derived from sports apps (Conrow, Wentz, Nelson, & Pettit, 2018; Fisher et al., 2018; Norman & Pickering, 2017; Norman, Pickering, & Castley, 2019; Oksanen, Bergman, Sainio, & Westerholm, 2015), suggesting that overall data accuracy and precision should follow the same patterns as those of other wiki data sources (Dorn, Törnros, & Zipf, 2015; See et al., 2013), even when the representativeness of these sources could be questioned – for example, not all visitors use such devices or services, many do not upload their tracks or photos, and many of those who do upload them do not share them outside their friends or family. Nevertheless, these new monitoring methods and the insights they provide are a powerful tool for P&RA managers, despite the existence of a multitude of established platforms (Nogueira Mendes & Pereira da Silva, 2018). Nowadays, almost everything that happens leaves a “digital geo-located footprint”, and recreation and free time are among the largest producers and sharers of voluntary GPS tracks, photos and comments – i.e. VGI.

Although VGI data has not yet been fully explored, it could certainly provide additional insights. Most studies were carried out at local scale, missing what can be learned from looking at the surrounding areas – namely, where people come from, or whether they act in the same way in other places. Regional studies used Tweets (Chua, Servillo, Marcheggiani, & Moere, 2016), Flickr photos (Fisher et al., 2018), or both types of data (Donahue et al., 2018; Hamstead et al., 2018), but these concern only point-located events. STRAVA data was used at regional scales, but mostly regarding urban mobility and transportation (Boss, Nelson, Winters, & Ferster, 2018; Hochmair, Bardin, & Ahmouda, 2019), which involves a different set of motivations and behaviours compared to recreational outdoor uses. Probably the main advantage that many VGI data sources provide which was not yet exploited is the fact that activities and behaviours can be linked to single, identified users. These data sources could therefore provide evidence regarding practitioners' commitment to recreational activities and their spatial behaviours.

1.1. Objectives

Taking mountain biking as a case study, the objective of this research was to evaluate VGI at a regional scale to monitor the activity within P&RAs in a metropolitan context. In detail, we sought to answer the following questions: 1) What are the main patterns of mountain-bike use in these areas? 2) What are the main differences in mountain biking in each riding area? 3) What are the main features of recreational users concerning web-share platforms? Since proper management of P&RAs requires detailed information about both uses and users, we wanted to analyse the extent to which sources of volunteered data can be used. Taking into account the fact that the data was produced by different users with different motivations can illuminate trends and perspectives within specific groups.

2. Materials and methods

2.1. Study area

The study area was the entire Lisbon Metropolitan Area (LMA), in Portugal. This includes Lisbon and 17 other municipalities in an area of 3002 km^2 with 2821 M inhabitants, i.e. 26.7% of Portugal's residents (Instituto Nacional de Estatística, 2021). The region is divided north–south by the Tagus River; the northern area is more densely occupied than the southern (1485 vs 500 residents/km^2). The population density for LMA as a whole is 962/residents/km^2, whereas the national average is 113/km^2.

LMA comprises several protected and green areas that function as peri-urban recreational parks, fulfilling the demand by residents and visitors alike for outdoor activities. The most visited are the Natural Parks of Sintra-Cascais (PNSC – A) and Arrábida (PNArr – B), the Protected Landscape of Costa da Caparica Fossil Cliff (PPAFCC – C), the Monsanto Forest Park (PFM – D), and the National Sports Center of Jamor (CDNJ – E) (Fig. 1). The first 3 are national protected areas that fall within IUCN Category V, while the last two are urban parks. Although each area has a different management objective, status and zoning plan, they are all used as recreational and bike-riding areas by residents and other users.

A short description of each park is given in Table I. This includes the park's status, creation date, total area, highest altitude point, number of residents from all census tracts that cross the park's boundaries (according to the last national census), proximity to Lisbon city center (according to Google Maps), a short description of the recreational opportunities and facilities within the park, and the park's policy regarding mountain-biking impacts and conflicts.

According to park managers, rangers, local municipalities, landowners and users, all parks have conflicts, and mountain biking is at the origin of some of these. Visible trail impacts can be directly attributed to mountain biking.

- Path degradation and soil erosion, as well as illegal and informal trails, are a common problem in A, B and D, which is of concern for the parks' managers and rangers;
- Freeriding and technical trail features are a serious risk in A, where they concern the park agency and the local municipalities;
- Trespassing that has led to social conflicts, especially between managers, landowners and users, is common to all five parks;
- Finally, E, being a dedicated sports complex, suffers from less pressure since trail maintenance is regular, but its popularity among the region's mountain bikers is high, due to its cross-country Olympic track.

Together, these parks represent 11.64% of the total LMA and feature

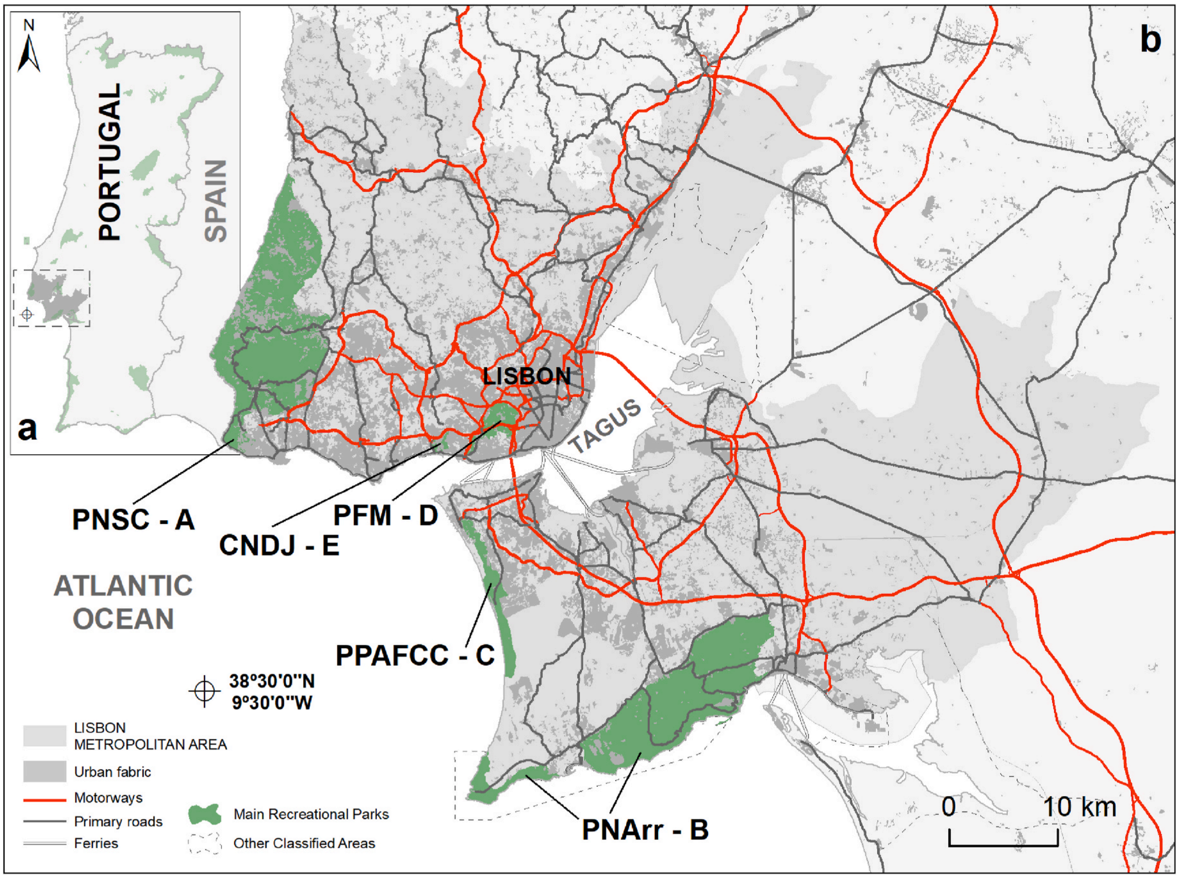

Fig. 1. a) Mainland Portugal and its national network of protected areas. b) Lisbon Metropolitan Area and its main recreational and protected areas: PNSC – A = Sintra-Cascais Natural Park; PNArr – B = Arrábida Natural Park; PPAFCC – C = Protected Landscape of Costa da Caparica Fossil Cliff; PFM – D = Monsanto Forest Park – D; CNDJ – E = Jamor National Sports Center.

Table 1
Description of the 5 main recreational parks of the Lisbon Metropolitan Area.

	PNSC – A	PNArr – B	APPAFCC – C	PFM – D	CDNJ – E
Status	Natural Park	Natural Park	Protected Landscape	Municipal Forest Park	National Sports Center
Decree	1981 Protected Landscape	1976	1971 National Forest of Mata dos Medos	1930s	1944
	1994 Natural Park	Natural Park	1984 Protected Landscape	Conversion of the previous common lands into forested area.	Several improvements and ampliations were done later
	2004 Management Plan	1982 & 2004 Management Plans	2008 Management Plan	Several improvements were done later	
Area (ha)	14,583	11,199	1599	900	204
Max. Altitude (m)	529	501	111	227	102
Residents (n)	39,986	9519	4091	10,709	2813
Distance from Lisbon by car (km/min)	30/30	35/55	20/35	0/0[a]	13/20
Official recreational opportunities	**Yes** Trekking and mountain biking trails Official Nature Sports Chart (under revision)	**No** One-off initiatives are suggested by local entities	**No** One-off initiatives are suggested by local entities	**Yes** Sports facilities; children's parks; walking, running & mountain-bike trails	**Yes** Sports facilities; children's parks; trails, cross-country tracks, etc.
Technical difficulties for mountain biking[b]	4/5	4/5	1/5	2/5	2/5
Mountain biking impacts and conflicts	Visible trail impacts, illegal/ informal trails, trespassing, technical trail features.	Visible trail impacts, illegal/informal trails, trespassing.	Visible trail impacts.	Visible trail impacts, illegal/ informal trails.	Visible trail impacts.
Future development for more outdoor use	Yes (within PNTN[c])	Yes (within PNTN[§])	Yes (within PNTN[c])	No	No

[a] It is within the city limits.
[b] On a scale of 1–5 according to altimetry, slope, trail hardness, mud, exposed roots, and rocks.
[c] PNTN: National Programme for Nature Tourism, which aims to further develop recreational uses and ecotourism in Portugal according to each protected area's carrying capacity.

the highest altitude points in the entire region.

2.2. Data collection

The dataset for this study was collected from GPSies.com (currently incorporated in AllTrails.com), using selective search queries as suggested by Nogueira Mendes, Dias, and Pereira da Silva (2014), specifically for mountain biking within LMA. This resulted in 16,173 individual tracks, of which 13,348 were within or crossed into the study area. Each track identified had 13 attributes (GPSies.com ID, track name, username, length, trip type, which activity/activities the track is suitable for, start-point postal code, altitude range, max z, min z, cumulative elevation gain, cumulative elevation loss, and notes), allowing different analyses. To avoid bias regarding the activity that was recorded or planned for each track, all tracks tagged as suitable for other activity/activities besides mountain biking were deleted following Santos, Nogueira Mendes, Farías-Torbidoni, Julião, and Pereira da Silva (2022). The submission/creation date for each track was registered for temporal analysis. Finally, the public profile of all identified users within the dataset was visited and their country of residence, registration date, number of tracks submitted, webpage and favourite activity were also registered.

2.3. Data treatment

Tracks were converted from GPX to Shapefile using QGis 2.18.15 and added to an ArcGIS Desktop 10.7 project. To ensure global accuracy, the number of track points, number of parts, track length, average distance between track points, and the start point Lat.-Long. Coordinates were computed to signal possible data noise. This process was iterated repeatedly, up to the last stage of preparing the final dataset. Tracks with extreme lengths, average track points that were too far apart, or that resulted from the merging of several rides in different places (and normally with lengths far greater than reasonable values) were individually checked and marked for deletion. Tracks in which the first track point was clearly outside the riding area (creating a straight line that crossed no riding locations – a common error produced by many handheld GPS units, which start to collect their track points from the last known location) were manually corrected. For the final dataset, all tracks previously identified as having a length above the 95th percentile were considered outliers and excluded. Finally, each track was labelled according to each mountain-biking area, resulting in 6 sub-datasets: one for each of the 5 areas, plus one for all tracks that were entirely outside these areas.

2.4. Data analysis

Data analysis was performed at regional and park scales and took into account both users and their tracks. Trip type (circular *vs* linear), number of users, average number of tracks per user, and descriptive track statistics (minimum, maximum, average and median lengths; standard deviation, 1st and 3rd quartiles, 95th percentile) were calculated, and the sub-datasets were compared with each other. The differences in the average length of the mountain-bike rides for each park were tested with one-way ANOVA, using Games-Howell multiple comparisons.

Users' level of commitment was evaluated through three indicators: 1) temporal behaviours were analysed at annual, monthly and weekly periods from the track submission dates; 2) the number of tracks from identified users included within the final dataset was compared to the total number of tracks submitted to GPSies.com by the same user; 3) users who chose to ride in two or more areas within LMA were identified from the data and their spatial displacement was evaluated.

Mountain-biking patterns in each P&RA were compared for their attractiveness, and mountain bikers' spatial preferences were investigated, using track-length histograms and 4 different indicators: 1) the percentage of mountain-bike rides starting within 250m of the designated mountain-biking area (including the parking facilities that often exist within these limits); 2) average percentages of ride length within/outside the riding area; 3) average distance covered by bike to the mountain-biking area; 4) maximum distance coverd by bike to the mountain-biking area.

Lastly, in order to infer the overall intensity of mountain biking in LMA, a more detailed spatial analysis was carried out for the entire study area by rasterizing the final dataset through a fishnet grid with a size of 25 m per pixel (following Nogueira Mendes et al. (2012).

3. Results

3.1. Dataset

The final dataset (after the manual editing, validation, and deletion of all tracks above the 95th percentile = 125.33 km) included 9523 tracks uploaded between 2006 and 2017, representing a total of 427,386 km of mountain biking. Overall analysis (Table II) shows that 60.57% of the rides targeted at least one of the P&RAs studied. 80.77% of all AML rides were round trips, with an average length of 44.87 km (± 22.93 km). On average, each of the 1319 users identified contributed 6.57 tracks to GPSies.com.

Within the original dataset, the maximum track length was 3313.73 km, with an average distance between track points of 800 m (a clear example of a route that had been drawn by a user, using the imagery services of this platform, but not actually followed; such tracks were deleted from the final dataset). Within this final dataset, 859 (9%) of all tracks (9,523) were uploaded or created by non-identified users, i.e. users who had deleted their accounts by the time the tracks were downloaded but who had still decided to share them.

For average riding distances, area C leads with 51.19 km (±23.68 km), followed by B, E and A. D has the shortest average distance, with 38.09 km (±22.26) km.

A one-way ANOVA test for track lengths in each riding area shows significant differences between them ($F = 52.887$; $P = 0.000$). Multiple comparisons using Games-Howell suggest that there are significant differences between area D's sub-dataset and those of all the other recreational areas ($P < 0.001$), and that C and B are also significantly different from A (Appendix 1).

4. Users' commitment

The visits to the users' public profiles showed, as expected, that most of them were from Portugal (98.03%, corresponding to 1293 users), followed by Germany (7 users), Spain (6), Russia (3 users), Belgium, Brazil, Netherlands (2 users), and Poland, France, Lithuania and Malta (1 user each). Fig. 2 shows the results from the temporal analysis performed within the dataset. On average, there was one new GPSies.com user every 3.34 days. April and May registered slightly more new users than any other months. Annual track submissions (2a) increased up to 2012, reaching a maximum of 1550. Sub-datasets B, C and E shared this trend, while areas A and D reached this maximum in 2013. Total monthly submissions (2b) ranged from a minimum of 640 in August to a maximum of 894 in November showing two peaks, one in spring and the other in autumn. Lastly, the days of the week with the highest number of submissions (2c) were Sundays (with 1473 tracks), followed by Mondays, Saturdays, Thursdays and Fridays.

Of the 1319 users identified responsible for 8664 of the tracks within the final dataset, 828 (62.77%) declared mountain biking to be their favourite activity among the 31 recreational activities available in this web-share service. In total, these users submitted 29,271 tracks, raising the average number of tracks submitted per user from 6.57 to 22.19. Of the same 1319 users, 14.10% (186) submitted only one track to this service, 26.08% (344) contributed only one track to the final dataset (but with many other tracks outside LMA), and 22.83% (301) did not

Table 2
General description of the study dataset regarding tracks used exclusively for mountain biking in LMA, collected @ GPSies.com.

	ORIGINAL dataset	FINAL dataset						
		TOTAL	Outside P&RAs	Crossing into				
				PNSC– A	PNArr– B	PPAFCC – C	PFM– D	CNDJ– E
Tracks and users (n)								
Tracks	10,027	9523	3755	1786	2805	436	810	155
Round trips	7806	7692	2930	1508	2291	324	653	122
One-way trips	2221	1831	825	278	514	112	157	33
Users	1372	1319	833	440	444	157	288	91
Avg. no. of tracks per user	6.66	6.57	4.06	3.68	5.82	2.48	2.6	1.49
Track length (km)								
Average	53.3	44.87	44.07	43.18	50.28	51.19	38.09	47.91
STDEV	74.73	22.93	24.59	21.89	21.56	23.68	22.26	28.81
Tracks submitted by unidentified users [as a % of the total number of tracks]								
	889 (9%)	859 (9%)	370 (10%)	165 (9%)	222 (8%)	47 (11%)	60 (7%)	19 (12%)

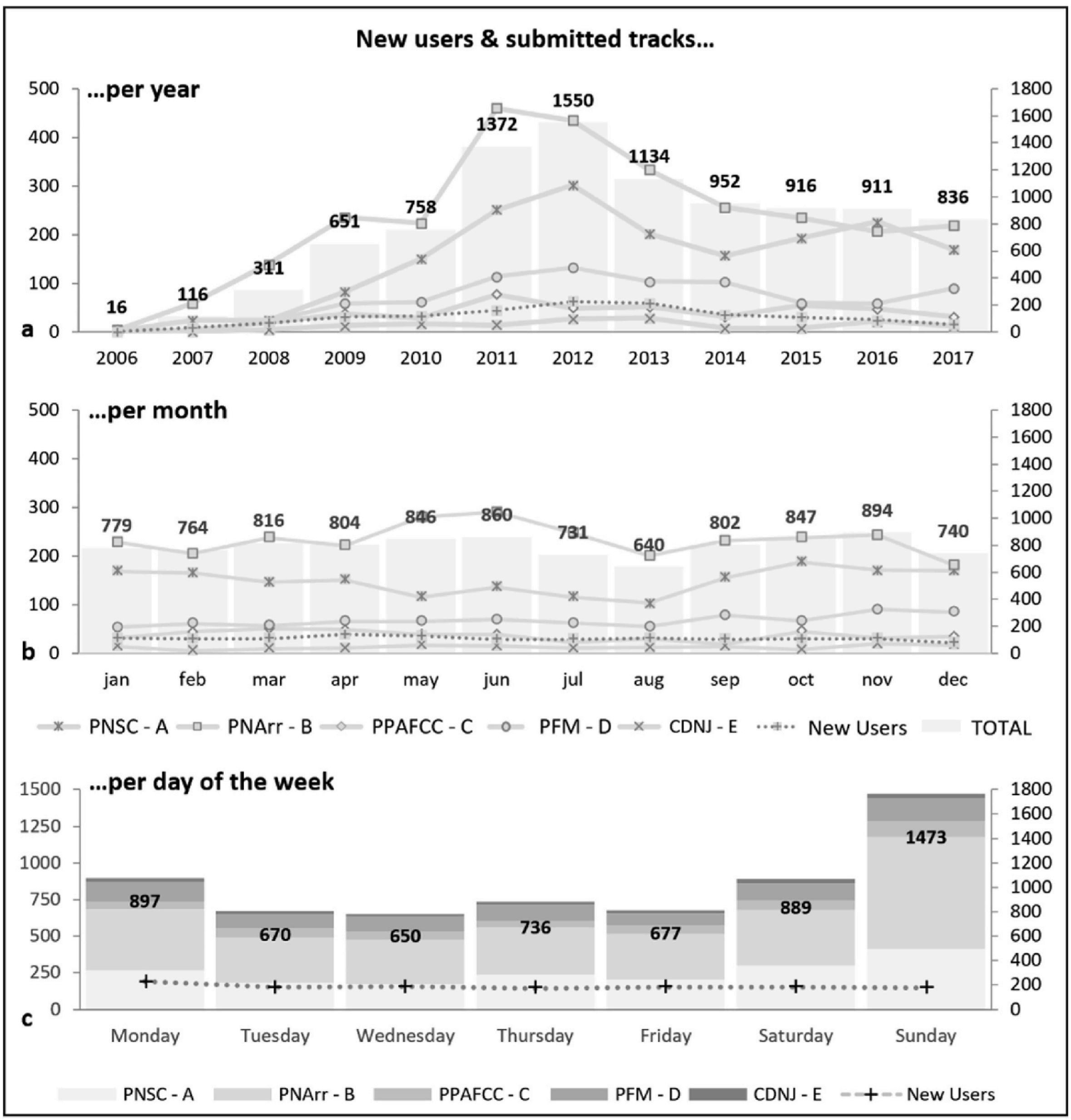

Fig. 2. Temporal patterns, new users and submitted tracks (a) per Year, (**b**) per month, (**c**) per day of the week, for the main recreational and protected parks of the Lisbon Metropolitan Area. Total numbers in Bold refer to the secondary axis on the right.

submit any tracks to GPSies.com other than the ones collected in this research.

Finally, most riders (65%) in fact targeted only one of the five areas for their rides within the main P&RAs of LMA, whereas the remaining 35% went to 2 or more (15% targeted 3 areas; 6% targeted 4; just 2% used all 5). The deeper analysis results in Table III show that 24% of mountain bikers in B also submitted tracks for area C, representing 68% of area C's users. The highest percentage of multi-area riders belongs to area E (with fewer users), of whom 79% also targeted D; B and A (with the same number of identified users) shared the same percentage of mountain bikers using more than one area: 32%. Riding exclusively outside of the main areas was also not uncommon, although these users were more dispersed, as seen earlier.

5. Riding patterns in the individual P&RAs

Track-length histograms show an almost normal distribution for the final dataset, as well as for areas A and B, with longer rides diminishing progressively after the average length is achieved (see Fig. 3). Area C sits between these two cases and area E, where the normal distribution is replaced by a multimodal series with a stronger presence of longer rides. Area D, which has shorter average rides, shows a flatter distribution but a similar number of submitted tracks (from 20 to 40 km).

Although most mountain biking within LMA targets its main P&RAs, Fig. 4 shows that rides starts all over the study area. Start points are distributed around the main residential areas, following the urban geography, with a clear difference between the north and the south sides of the Tagus river, as south-side riders are keener to target the southern region P&RA.

Other riding behaviours and preferences also differ between mountain-biking areas. Area A has the highest percentage of rides starting within 250m of the park (51%), followed by D, B and E, and finally C with 13%. The average distance covered within each P&RA is also different. Again, area A records the highest value, with 74% of the rides being completed within the park, followed by the same pattern (D, B, E, C). The average riding distance to get to the limits of each P&RA ranges from 3.6 km (area D) to 6.2 km (area B). The greatest distance travelled to arrive at a park was 55.7 km (area A).

5.1. Spatial analysis

Fig. 5 shows the level of detailed VGI derived from mountain bikers' GPS tracks which can be used by park managers. The use-intensity map produced from the fishnet analysis for area B (Fig. 5a) shows that the park divides into 3 sectors, according to the density of the trails. There is a clear preference for unpaved surfaces and, overall, mountain biking follows the area's network of trails and paved roads. Nevertheless, some undesirable behaviour, such as trespassing, and informal trails can be observed. Fig. 5b–e shows the detailed information that can be extracted from these datasets. Straight lines from GPS errors do not interfere with the use-intensity results, but single lines that could represent illegal use stand out. Finally, the main entrances and hotspots are easy to identify.

6. Discussion

VGI is accepted as a valid source of information for many activities, from mapping (Goodchild, 2007; See et al., 2013, 2015) and community planning (Giuffrida, Le Pira, Inturri, & Ignaccolo, 2019; Wolf, Wohlfart, Brown, & Bartolomé Lasa, 2015) to crowdsourced/citizen science projects (See et al., 2016). Previously, spatial data for monitoring recreational activities would be derived from two types of geographical data, such as GPS logs and remote sensing, or information provided directly by visitors (Riungu, Peterson, Beeco, & Brown, 2018). Nowdays, VGI is also a well-established data source for monitoring popular recreational activities and has special relevance for activities such as mountain biking which count numerous practitioners.

Comparing our results to what is known about mountain biking within the study areas could strengthen the validation of web-share services and sports apps as data sources for monitoring, whilst acknowledging that registered users seem to be more committed than the average mountain bikers. This is suggested by the fact that monthly and weekly histograms are flatter than for other common recreational activities at these latitudes. Seasonal patterns for Geocaching in area B (Martins, 2014), as well as trail running (Valente, 2019) and mountain-biking events in Portugal and Spain (Nogueira Mendes et al., 2021; Segui Urbaneja & Farías Torbidoni, 2018), have two seasonal peaks: in spring and after the summer holidays. In terms of day-to-day use, data from automatic counters for area B show that Sunday is the most popular day for mountain-biking, with twice the average Saturday number, and up to 6 to 7 times more than the average numbers for working days (Nogueira Mendes et al., 2012). Contrary to what was expected, within this dataset Monday (and not Saturday) is the second most popular day. A possible explanation is that before the advent of smartphones and sports apps, affordable mobile data plans, and their mass use, to record of a GPS track required dedicated and expensive equipment, and to share a track required a later upload to these services. Sometimes this would happen only after midnight, i.e. during the next day.

Annual submissions tell us more about the popularity of these services themselves than about overall mountain-biking use or user commitment, which could be due to the current widespread use of smartphones, smartwatches and sports apps that are always connected. The fall-off of new users and tracks submitted between 2012 and 2013 (see Fig. 2a) coincided with the mass popularization of Smartphones in Portugal, and of sports apps such as Strava, Endomondo and others, the use of which correlates closely with the rise of other social media. These new apps and platforms may also include extra features such as training supervision and fitness analysis. The popularity of these apps and the services they offer follow trends (Campelo & Nogueira Mendes, 2016) and word-of-mouth promotion among friends and acquaintances. Showing "my" rides is surely important among "my" friends and peers. This explains why any real estimate or evaluation of recreational activities has not yet been carried out using sports apps or web-share platforms, although these correlate with on-site counts (Norman & Pickering, 2017, 2019) at a local scale.

It is also important to realize that each track might represent more

Table 3
Percentage of mountain bikers from each protected or recreational area who also ride in other areas of LMA. Note: Numbers refer to identified users.

… who ride in		% of Mountain bikers from:					
		PNSC– A	PNArr– B	PPAFCC– C	PFM– D	CDNJ– E	Outside P&RA
		440	444	157	288	91	833
PNSC – A	440	–	32%	41%	48%	67%	29%
PNArr – B	444	32%	–	68%	34%	37%	27%
PPAFCC – C	157	15%	24%	–	19%	25%	11%
PFM – D	288	31%	22%	35%	–	79%	21%
CDNJ – E	91	14%	8%	15%	25%	–	7%
Outside P&RA	833	55%	52%	59%	61%	66%	–

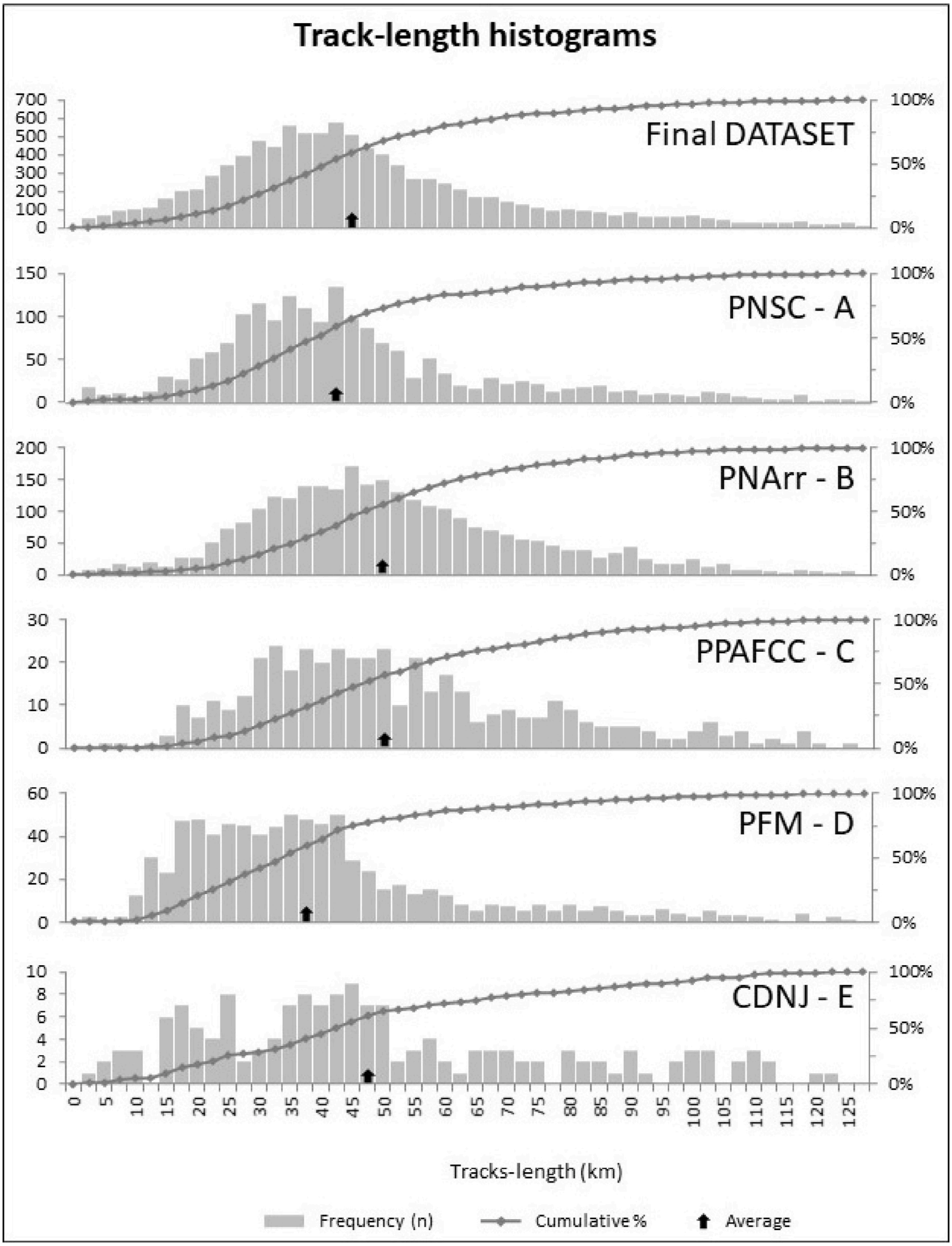

Fig. 3. Track-length histograms for the final dataset and each protected and recreational area studied.

than just one user, since mountain biking is mainly a social activity. According to Campelo and Brito (2015), the average group size of mountain bikers in area A is around 5–6, meaning that every single track that creates or uses an illegal or informal trail, could, if done repeatedly, lead to serious conflicts and impacts.

Regarding overall differences among the parks studied, the results suggest two types of mountain-biking places: main destinations and areas that riders simply pass through. Parks A and B are good examples of destinations, offering more off-road and trail choices and steeper climbs, which results in higher numbers of rides taking place within the park's boundaries, and, in many cases, in bikers covering more than 20/30 km to get to their favourite trails. Areas E and C, on the other hand, attract fewer mountain bikers due to their smaller size, but also due to a lack of choices. Area D, which has smallest average ride length, is a good

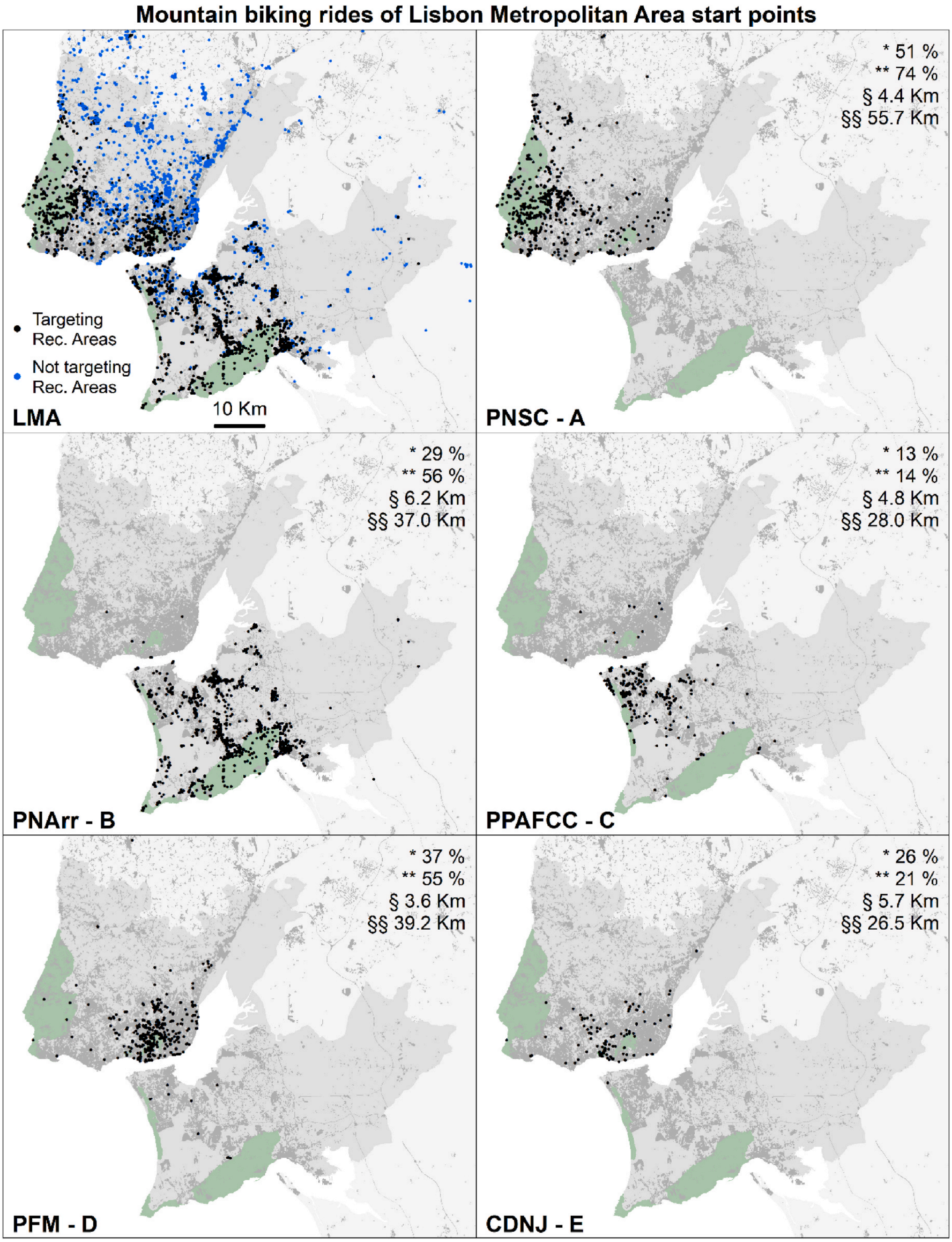

Fig. 4. Start points of mountain-bike rides for each of the main protected and recreational areas of the Lisbon Metropolitan Area. * Percentage of rides that start inside or within 250m of the mountain-biking area; ** Average percentage of ride within the mountain-biking area; § Average ride distance to arrive at the mountain-biking area; §§ Maximum ride distance to arrive at the mountain-biking area.

place for shorter/faster rides or beginners (as suggested by the flatter histogram). This area seems to be in the middle range for attractiveness, although it is more comparable to the natural parks in terms of trail options. The recreational facilities here make D a good choice for mountain bikers who need to make their rides compatible with their families. Although the Tagus River splits LMA's main recreational areas into north and south sides, some rides start on one side of the river and target areas on the other, with mountain bikers using the ferry crossings, a behaviour that is more common in area C.

Plotting these datasets into a GIS as shown in Fig. 5 makes the main entrances and hotspots apparent. These locations could be used to monitor real numbers of users, either through automatic counters or

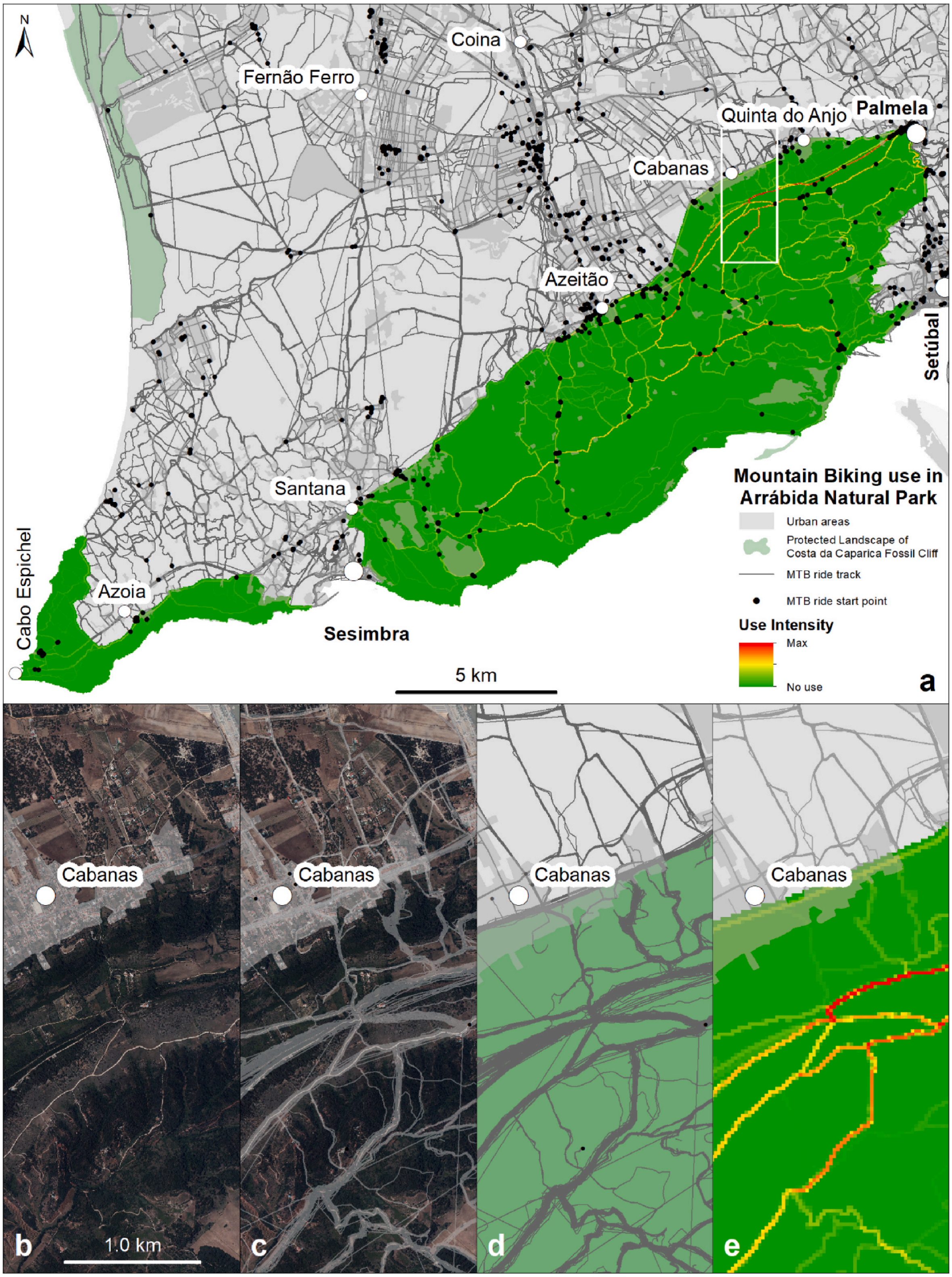

Fig. 5. Mountain biking in PNArr – B according to the 2805 tracks that crossed this protected area. **a**) Mountain-biking intensity for the entire park, showing the detailed road and trail network that can be generated from VGI; **b**) high-resolution imagery showing the most popular trails in Arrábida; **c**) high-resolution imagery and tracks from the final dataset; **d**) final dataset plotted against the GIS project base map; **e**) detail of the fishnet analysis rasterized to a pixel size of 25 × 25 m.

through on-site surveys, and to raise awareness while encouraging more positive behaviours. Fig. 5 also shows that even if off-road and certain single tracks might be the favourite choices for most dedicated users, within a major metropolitan area these are insufficient for a full Sunday-morning ride, and "on-road" use is common inside and/or outside each R&PA.

This dataset has nevertheless a major flaw where regional analysis is concerned. While at each park all temporal and spatial results are consistent and can be understood and explained, total retrieved tracks for each area don't necessarily equate to its overall use volume: B has the highest number of tracks, but A is used much more for mountain biking. It is also the area where the most conflicts occur. Area A has a higher density of residents, and most riders might even consider this place their "backyard". For those who ride in Area B, who tend to come from greater distances, a GPS might be a good tool to limit lengthy detours due to mistakes. Among riders from the southern region, the popularity of GPSies.com itself can also be linked to the popularity of an already existing local web forum (forumbtt.net) dedicated to mountain biking and used to share GPS tracks. Local differences between favourite web-share services or the popularity of particular sports apps, or even the urge to keep a record of each ride, are also possible explanations for this flaw.

Future research using these data sources should consider shifts and trends, concerning not just recreational uses but also within social media, technology, new sports, or even new gear. In Portugal, for example, it seems that mountain biking has lost practitioners to trail running (Julião, Valente, & Nogueira Mendes, 2018) and *gran fondo* (mass participation road cycling events) which has increased in popularity. Will these be replaced in the future by e-bikers, for example? Will users and behaviours change? Will we see older riders, longer distances (Ling, Cherry, MacArthur, & Weinert, 2017), and higher participation by women (Van Cauwenberg, De Bourdeaudhuij, Clarys, De Geus, & Deforche, 2018)? Or will road and off-road cyclists join in what seems to be the next new trend – all-in-one gravel bikes? And a major challenge still remains to be addressed: to understand how many users these platforms and apps represent, and whether these data sources could be used to count riders, runners, trekkers etc. At the current moment, as stated by Monz, Mitrovich, D'Antonio, and Sisneros-Kidd (2019) location based services can provide an estimate of visitor use but not yet a direct count.

7. Conclusions

Exploiting VGI to monitor recreational behaviour at a metropolitan scale has illustrated that it is of use in more than just mapping. Users are committed to web-share platforms, and these services reflect their general behaviours and preferences. Although the collection of big datasets might be laborious, data treatment and analysis are cost-effective in providing insights that are detailed enough to allow action to be taken on environmental impacts or conflicts between users or stakeholders (Campelo & Nogueira Mendes, 2016). Within the multitude of web-share platforms and sports apps available, results may vary regarding other activities and from place to place according to social trends, but the potential value of the digital geo-located footprint is undeniable.

This study has also shown that any management actions within peri-urban parks that place an emphasis on sports activities such as mountain biking need to consider the surrounding areas as suggested by Greer, Day, and McCutcheon (2017). People mainly ride close to their place of residence, within their available leisure time, as has been pointed out by other studies (Farías-Torbidoni & Morera, 2020), but cycling to other areas is common, and even cycling outside P&RAs. Such behaviours can also relieve pressure on more sensitive areas, meaning that an appropriate offer of recreational uses in a peri-urban context should be planned at a larger scale and not just for each park or individual area.

Whatever happens, the territory available for these activities is more difficult to change, which makes monitoring uses essential if managers of P&RAs are to accomplish their main aims, among which recreational activities are just one small element. VGI has the potential to be a good helping hand in monitoring and managing the recreational use of parks.

CRediT authorship contribution statement

Ricardo M. Nogueira Mendes: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Visualization. **Estela Inés Farías-Torbidoni:** Methodology, Writing – review & editing, Supervision. **Carlos Pereira da Silva:** Writing – review & editing, Supervision, Funding acquisition.

Declaration of competing interest

None.

Acknowledgments

This publication was made with the support of CICS.NOVA-Interdisciplinary Centre of Social Sciences of the NOVA University of Lisbon, UIDB/04647/2020, (financial support of FCT/MCTES through National funds) and National Institute of Physical Education of Catalonia (INEFC) – University of Lleida.

APPENDIX 1

ANOVA - Track Length

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	141,342,543,637.496	5	28,268,508,727.499	52.887	0.000
Within Groups	5,206,620,880,109.790	9741	534,505,787.918		
Total	5,347,963,423,747.280	9746			

ROBUST TESTS OF EQUALITY OF MEANS - Track Length

	Statistic[a]	df1	df2	Sig.
Welch	57.166	5	1150.406	0.000

Asymptotically F distributed.

MULTIPLE COMPARISONS Dependent Variable: Games-Howell

(I) Reecreational & Protected Area		Mean Diff. (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
PNSC - A	PNArr - B	−7106.556*	659.018	0	−8985.54	−5227.58
	PPAFCC - C	−8014.405*	1247.890	0	−11,581.54	−4447.27
	PFM - D	5081.262*	938.634	0	2403.05	7759.47
	CDNJ - E	−4737.717	2378.485	0.351	−11,593.85	2118.41
	OUTrecre&protec	−852.15	655.563	0.785	−2721.24	1016.94
PNArr - B	PNSC - A	7106.556*	659.018	0	5227.58	8985.54
	PPAFCC - C	−907.85	1205.995	0.975	−4356.69	2540.99
	PFM - D	12,187.818*	882.172	0	9670.06	14,705.57
	CDNJ - E	2368.839	2356.774	0.916	−4427.61	9165.29
	OUTrecre&protec	6254.406*	571.801	0	4624.45	7884.37
PPAFCC - C	PNSC - A	8014.405*	1247.890	0	4447.27	11,581.54
	PNArr - B	907.85	1205.995	0.975	−2540.99	4356.69
	PFM - D	13,095.667*	1378.823	0	9157.37	17,033.96
	CDNJ - E	3276.689	2584.049	0.802	−4149.14	10,702.52
	OUTrecre&protec	7162.255*	1204.110	0	3718.74	10,605.77
PFM - D	PNSC - A	−5081.262*	938.634	0	−7759.47	−2403.05
	PNArr - B	−12,187.818*	882.172	0	−14,705.57	−9670.06
	PPAFCC - C	−13,095.667*	1378.823	0	−17,033.96	−9157.37
	CDNJ - E	−9818.978*	2449.717	0.001	−16,871.58	−2766.37
	OUTrecre&protec	−5933.412*	879.594	0	−8443.83	−3423.00
CDNJ - E	PNSC - A	4737.717	2378.485	0.351	−2118.41	11,593.85
	PNArr - B	−2368.839	2356.774	0.916	−9165.29	4427.61
	PPAFCC - C	−3276.689	2584.049	0.802	−10,702.52	4149.14
	PFM - D	9818.978*	2449.717	0.001	2766.37	16,871.58
	OUTrecre&protec	3885.567	2355.810	0.567	−2908.23	10,679.36
OUTrecre&protec	PNSC - A	852.15	655.563	0.785	−1016.94	2721.24
	PNArr - B	−6254.406*	571.801	0	−7884.37	−4624.45
	PPAFCC - C	−7162.255*	1204.110	0	−10,605.77	−3718.74
	PFM - D	5933.412*	879.594	0	3423.00	8443.83
	CDNJ - E	−3885.567	2355.810	0.567	−10,679.36	2908.23

a The mean difference is significant at the 0.05 level.

References

Balmford, A., Beresford, J., Green, J., Naidoo, R., Walpole, M., & Manica, A. (2009). A global perspective on trends in nature-based tourism. *PLoS Biology, 7*(6), Article e1000144. https://doi.org/10.1371/journal.pbio.1000144

Boman, M., Fredman, P., Lundmark, L., & Ericsson, G. (2013). Outdoor recreation - a necessity or a luxury? Estimation of engel curves for Sweden. *Journal of Outdoor Recreation and Tourism, 3–4*, 49–56. https://doi.org/10.1016/j.jort.2013.09.002

Boss, D., Nelson, T., Winters, M., & Ferster, C. J. (2018). Using crowdsourced data to monitor change in spatial patterns of bicycle ridership. *Journal of Transport & Health, 9*, 226–233. https://doi.org/10.1016/j.jth.2018.02.008. November 2017.

Braun, V. (2020). The Nature Park movement in Austria – from recreational areas to (wards) model regions for sustainable development. *Eco.Mont (Journal on Protected Mountain Areas Research), 12*(1), 64–69. https://doi.org/10.1553/eco.mont-12-1s64

Campelo, & Brito, M. (2015). *Caracterização do BTT no parque natural de Sintra-cascais: Um contributo para a revisão da carta de Desporto de Natureza do PNSC*. Universidade de Lisboa.

Campelo, M. B., & Nogueira Mendes, R. M. (2016). Comparing webshare services to assess mountain bike use in protected areas. *Journal of Outdoor Recreation and Tourism, 15*, 82–88. https://doi.org/10.1016/j.jort.2016.08.001

Chua, A., Servillo, L., Marcheggiani, E., & Moere, A. V. (2016). Mapping Cilento: Using geotagged social media data to characterize tourist flows in southern Italy. *Tourism Management, 57*, 295–310. https://doi.org/10.1016/j.tourman.2016.06.013

Ciesielski, M., Sterenczak, K., & Balazy, R. (2019). Application of the Volunteered Geographic Information data to monitor traffic in the forest area. *Sylwan, 163*(1), 80–88.

Colléony, A., Prévot, A. C., Saint Jalme, M., & Clayton, S. (2017). What kind of landscape management can counteract the extinction of experience? *Landscape and Urban Planning, 159*, 23–31. https://doi.org/10.1016/j.landurbplan.2016.11.010

Conrow, L., Wentz, E., Nelson, T., & Pettit, C. (2018). Comparing spatial patterns of crowdsourced and conventional bicycling datasets. *Applied Geography, 92*(December 2017), 21–30. https://doi.org/10.1016/j.apgeog.2018.01.009

Costanza, R., D'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., et al. (1997). The value of the world's ecosystem services and natural capital. *Nature, 387*(6630), 253–260. https://doi.org/10.1038/387253a0

De Valck, J., Landuyt, D., Broekx, S., Liekens, I., De Nocker, L., & Vranken, L. (2017). Outdoor recreation in various landscapes: Which site characteristics really matter? *Land Use Policy, 65*(April), 186–197. https://doi.org/10.1016/j.landusepol.2017.04.009

Donahue, M. L., Keeler, B. L., Wood, S. A., Fisher, D. M., Hamstead, Z. A., & McPhearson, T. (2018). Using social media to understand drivers of urban park visitation in the Twin Cities, MN. *Landscape and Urban Planning, 175*(March), 1–10. https://doi.org/10.1016/j.landurbplan.2018.02.006

Dorn, H., Törnros, T., & Zipf, A. (2015). Quality evaluation of VGI using authoritative data—a comparison with land use data in southern Germany. *ISPRS International Journal of Geo-Information, 4*(3), 1657–1671. https://doi.org/10.3390/ijgi4031657

Farías-Torbidoni, E. I., & Morera, S. (2020). *Estudi d'afluència, freqüentació i caracterització dels usuaris- visitants del parc natural de la serra de collserola 2019*. https://doi.org/10.13140/RG.2.2.27890.12485

Fisher, D. M., Wood, S. A., White, E. M., Blahna, D. J., Lange, S., Weinberg, A., et al. (2018). Recreational use in dispersed public lands measured using social media data and on-site counts. *Journal of Environmental Management, 222*, 465–474. https://doi.org/10.1016/j.jenvman.2018.05.045

Giuffrida, N., Le Pira, M., Inturri, G., & Ignaccolo, M. (2019). Mapping with stakeholders: An overview of public participatory GIS and VGI in transport decision-making. *ISPRS International Journal of Geo-Information, 8*(4). https://doi.org/10.3390/ijgi8040198

Goodchild, M. F. (2007). Citizens as sensors: The world of volunteered geography. *Geojournal, 69*(4), 211–221. https://doi.org/10.1007/s10708-007-9111-y

Graf, R. F., Signer, C., Reifler-Bächtiger, M., Wyttenbach, M., Sigrist, B., & Rupf, R. (2018). Wildlife and humans in outdoor recreational areas near cities. *Wildtier Und Mensch Im Naherholungsraum, 13*(2), 8. https://doi.org/10.5281/ZENODO.1168451

Greer, K., Day, K., & McCutcheon, S. (2017). Efficacy and perception of trail use enforcement in an urban natural reserve in San Diego, California. *Journal of Outdoor Recreation and Tourism, 18*(February), 56–64. https://doi.org/10.1016/j.jort.2017.02.002

Hamstead, Z. A., Fisher, D., Ilieva, R. T., Wood, S. A., Mcphearson, T., & Kremer, P. (2018). Geolocated social media as a rapid indicator of park visitation and equitable park access. *Computers, Environment and Urban Systems, 72*, 38–50. https://doi.org/10.1016/j.compenvurbsys.2018.01.007. July 2017.

Hochmair, H. H., Bardin, E., & Ahmouda, A. (2019). Estimating bicycle trip volume for Miami-Dade county from Strava tracking data. *Journal of Transport Geography, 75*, 58–69. https://doi.org/10.1016/j.jtrangeo.2019.01.013

Instituto Nacional de Estatística, I. P. (2021). *CENSOS 2011. Resultados definitivos*. Portugal. Censos INE. Instituto Nacional de Estatística, I.

Julião, R. P., Valente, M., & Nogueira Mendes, R. (2018). Issues on Trail runners, Trail running and recreational and protected areas in Portugal. In J. Dehez, G. Lambert, L. Ginelli, & K. B. hadj Abdallah (Eds.), *The 9th international conference on monitoring and management of visitors in recreational and protected areas (MMV)* (pp. 290–293). Bordeaux: Bordeaux Sciences Agro; IRSTEA.

Ling, Z., Cherry, C. R., MacArthur, J. H., & Weinert, J. X. (2017). Differences of cycling experiences and perceptions between e-bike and bicycle users in the United States? *Sustainability, 9*(9), 1–18. https://doi.org/10.3390/su9091662

Manning, R. E. (2014). Research to guide management of outdoor recreation and tourism in parks and protected areas. *Koedoe, 56*(2), 1–7. https://doi.org/10.4102/koedoe.v56i2.1159

Marion, J. L., Leung, Y.-F., Eagleston, H., & Burroughs, K. (2016). A review and synthesis of recreation ecology research findings on visitor impacts to wilderness and

protected natural areas. *Journal of Forestry, 114*(3), 352–362. https://doi.org/10.5849/jof.15-498
Martins, G. F. de M. (2014). *Caracterização da atividade de Geocaching no Parque Natural da Arrábida*. Retrieved from http://repositorio.ul.pt/handle/10451/16131.
Miller, J. R., & Hobbs, R. J. (2002). Conservation where people live and work. *Conservation Biology, 16*(2), 330–337.
Monz, C., Mitrovich, M., D'Antonio, & Sisneros-Kidd, A. (2019). Using mobile device data to estimate visitation in parks and protected areas: An example from the nature reserve of orange county, California. *Journal of Park and Recreation Administration*. https://doi.org/10.18666/JPRA-2019-9899
Nogueira Mendes, R. M., Dias, P., & Pereira da Silva, C. (2014). Profiling MTB users' preferences within protected areas through Webshare services. In M. Reimann, K. Sepp, E. Pärna, & R. Tuula (Eds.), *The 7th international conference on monitoring and management of visitors in recreational and protected areas (MMV) local community and outdoor recreation* (pp. 166–168). Tallinn: Department of Leisure Sciences.
Nogueira Mendes, R. M., Farías-Torbidoni, E. I., & Pereira da Silva, C. (2021). Eventos de bicicleta de montanha em Portugal: Características, distribuição temporal e espacial e ocorrência sobre a rede nacional de áreas protegidas e classificadas. RETOS. Nuevas tendencias en educación física. *Deporte y Recreación*, (39), 216–223. https://doi.org/10.47197/retos.v0i39.78368
Nogueira Mendes, R., & Pereira da Silva, C. (2018). Looking back at recreational activities in protected areas using VGI from web-share services. In J. Dehez, G. Lambert, L. Ginelli, & K. B. hadj Abdallah (Eds.), *The 9th international conference on monitoring and management of visitors in recreational and protected areas (MMV), 95* pp. 140–142). Bordeaux: Bordeaux Sciences Agro; IRSTEA.
Nogueira Mendes, R., Silva, A., Grilo, C., Rosalino, L. M., & Pereira da Silva, C. (2012). MTB monitoring in Arrábida natural park, Portugal. In P. Fredman, M. Stenseke, H. Liljendahl, A. Mossing, & D. Laven (Eds.), *The 6th international conference on monitoring and management of visitors in recreational and protected areas (MMV)* (pp. 32–33) (Stockholm).
Norman, P., & Pickering, C. M. (2017). Using volunteered geographic information to assess park visitation: Comparing three on-line platforms. *Applied Geography, 89* (November), 163–172. https://doi.org/10.1016/j.apgeog.2017.11.001
Norman, P., & Pickering, C. M. (2019). Factors influencing park popularity for mountain bikers, walkers and runners as indicated by social media route data. *Journal of Environmental Management, 249*(August), Article 109413. https://doi.org/10.1016/j.jenvman.2019.109413
Norman, P., Pickering, C. M., & Castley, G. (2019). What can volunteered geographic information tell us about the different ways mountain bikers, runners and walkers use urban reserves? *Landscape and Urban Planning, 185*(February), 180–190. https://doi.org/10.1016/j.landurbplan.2019.02.015
Oksanen, J., Bergman, C., Sainio, J., & Westerholm, J. (2015). Methods for deriving and calibrating privacy-preserving heat maps from mobile sports tracking application data. *Journal of Transport Geography, 48*, 135–144. https://doi.org/10.1016/j.jtrangeo.2015.09.001
Perić, M., & Slavić, N. (2019). Event sport tourism business models: The case of trail running. *Sport, Business and Management: International Journal, 9*(2), 164–184. https://doi.org/10.1108/sbm-05-2018-0039
Pickering, C. M. (2010). Ten factors that affect the severity of environmental impacts of visitors in protected areas. *Ambio, 39*(1), 70–77. https://doi.org/10.1007/s13280-009-0007-6
Pickering, C. M., Hill, W., Newsome, D., & Leung, Y.-F. (2010). Comparing hiking, mountain biking and horse riding impacts on vegetation and soils in Australia and the United States of America. *Journal of Environmental Management, 91*(3), 551–562. https://doi.org/10.1016/j.jenvman.2009.09.025
Pickering, C., Walden-Schreiner, C., Barros, A., & Rossi, S. D. (2020). Using social media images and text to examine how tourists view and value the highest mountain in Australia. *Journal of Outdoor Recreation and Tourism, 29*. https://doi.org/10.1016/j.jort.2019.100252. September 2019.
Riungu, G. K., Peterson, B. A., Beeco, J. A., & Brown, G. (2018). Understanding visitors' spatial behavior: A review of spatial applications in parks. *Tourism Geographies, 20* (5), 833–857. https://doi.org/10.1080/14616688.2018.1519720
Rosário, I. T., Rebelo, R., Cardoso, P., Segurado, P., Mendes, R. N., & Santos-Reis, M. (2019). Can geocaching be an indicator of cultural ecosystem services? The case of the montado savannah-like landscape. *Ecological Indicators, 99*, 375–386. https://doi.org/10.1016/j.ecolind.2018.12.003. April 2019.
Santos, T., Nogueira Mendes, R., Farías-Torbidoni, E. I., Julião, R. P., & Pereira da Silva, C. (2022). Volunteered geographical information and recreational uses within metropolitan and rural contexts. *ISPRS International Journal of Geo-Information, 11*, 144. https://doi.org/10.3390/ijgi11020144
Santos, T., Nogueira Mendes, R., & Vasco, A. R. (2016). Recreational activities in urban parks: Spatial interactions among users. *Journal of Outdoor Recreation and Tourism, 15*, 1–9. https://doi.org/10.1016/j.jort.2016.06.001
See, L., Comber, A., Salk, C., Fritz, S., van der Velde, M., Perger, C., et al. (2013). Comparing the quality of crowdsourced data contributed by expert and non-experts. *PLoS One, 8*(7), 1–11. https://doi.org/10.1371/journal.pone.0069958
See, L., Fritz, S., Perger, C., Schill, C., McCallum, I., Schepaschenko, D., et al. (2015). Harnessing the power of volunteers, the internet and Google Earth to collect and validate global spatial information using Geo-Wiki. *Technological Forecasting and Social Change, 98*, 324–335. https://doi.org/10.1016/j.techfore.2015.03.002
See, L., Mooney, P., Foody, G., Bastin, L., Comber, A., Estima, J., et al. (2016). Crowdsourcing, citizen science or volunteered geographic information? The current state of crowdsourced geographic information. *ISPRS International Journal of Geo-Information, 5*(5), 55. https://doi.org/10.3390/ijgi5050055
Segui Urbaneja, J., & Farías Torbidoni, E. I. (2018). El trail running (carreras de o por montaña) en España. Inicios, evolución y (actual) estado de la situación. RETOS. Nuevas Tendencias En Educación Física. *Deporte y Recreación, 33*(33), 123–128. Retrieved from https://recyt.fecyt.es/index.php/retos/article/view/56462/35797.
Triguero-Mas, M., Dadvand, P., Cirach, M., Martínez, D., Medina, A., Mompart, A., et al. (2015). Natural outdoor environments and mental and physical health: Relationships and mechanisms. *Environment International, 77*, 35–41. https://doi.org/10.1016/j.envint.2015.01.012
Valente, M. S. da S. (2019). *Desportos de Natureza e Espaços Naturais: Análise Espacial do Trail Running em Portugal*. Universidade Nova de Lisboa.
Van Cauwenberg, J., De Bourdeaudhuij, I., Clarys, P., De Geus, B., & Deforche, B. (2018). Older E-bike users: Demographic, health, mobility characteristics, and cycling levels. *Medicine & Science in Sports & Exercise, 50*(9), 1780–1789. https://doi.org/10.1249/MSS.0000000000001638
Walden-Schreiner, C., Leung, Y.-F., & Tateosian, L. (2018a). Digital footprints: Incorporating crowdsourced geographic information for protected area management. *Applied Geography, 90*, 44–54. https://doi.org/10.1016/j.apgeog.2017.11.004
Walden-Schreiner, C., Rossi, S. D., Barros, A., Pickering, C., & Leung, Y.-F. (2018b). Using crowd-sourced photos to assess seasonal patterns of visitor use in mountain-protected areas. *Ambio, 47*(7), 781–793. https://doi.org/10.1007/s13280-018-1020-4
Wolf, I. D., Wohlfart, T., Brown, G., Lasa, A. B., & Bartolomé Lasa, A. (2015). The use of public participation GIS (PPGIS) for park visitor management: A case study of mountain biking. *Tourism Management, 51*, 112–130. https://doi.org/10.1016/j.tourman.2015.05.003
Worboys, G., Lockwood, M., Kothari, A., Feary, S., & Pulsford, I. (2015). *Protected Area Governance and Management. IUCN*. Camberra: ANU Press. https://doi.org/10.1017/CBO9781107415324.004

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