Tourism Recreation Research

ISSN: 0250-8281 (Print) 2320-0308 (Online) Journal homepage: www.tandfonline.com/journals/rtrr20

Using GPS tracking data from mobile fitness apps to understand user behaviour in protected areas

Jorge Costa, Alberto Gomes, Martin Stokes & Miguel Saraiva

To cite this article: Jorge Costa, Alberto Gomes, Martin Stokes & Miguel Saraiva (01 Aug 2025): Using GPS tracking data from mobile fitness apps to understand user behaviour in protected areas, Tourism Recreation Research, DOI: 10.1080/02508281.2025.2528241

To link to this article: https://doi.org/10.1080/02508281.2025.2528241

Published online: 01 Aug 2025.

TOURISM RECREATION RESEARCH
https://doi.org/10.1080/02508281.2025.2528241

Using GPS tracking data from mobile fitness apps to understand user behaviour in protected areas

Jorge Costa [a,b], Alberto Gomes [a,b], Martin Stokes [c] and Miguel Saraiva [a,b]

[a]Department of Geography, Faculty of Arts and Humanities, University of Porto Porto, Portugal; [b]CEGOT, Faculty of Arts and Humanities, University of Porto Porto, Portugal; [c]School of Geography, Earth and Environmental Sciences, University of Plymouth, Plymouth, UK

ABSTRACT

Protected areas are important environmental conservation sites, but their sustainability depends on effective management to mitigate the negative impacts of nature–based tourism. Data from Mobile fitness apps (MFAs) provide researchers and stakeholders with detailed spatiotemporal information regarding visitor movements, thereby facilitating a comprehensive understanding of visitor behaviour, the implementation of effective monitoring strategies, and the minimisation of tourism–related impacts. Considering the novelty and growth of studies exploring MFAs to understand recreational use in protected areas, it's essential to integrate this emerging field of data science into existing knowledge and establish MFA–based monitoring. A detailed analysis of 26 publications, published between 2012 and 2023, was performed to explore who conducts the research, the main sources of knowledge, where the research is conducted, the core research questions, the data sources used, and which methodologies are employed. Results show that research is primarily conducted by European, Chinese, and Australian scholars within a collaboration network that remains underdeveloped. Studies are mostly influenced by research published after 2010 and focus on visitors' spatiotemporal behaviour analysis and environmental impact assessment. MFAs function as surrogates for on–site visit counts, offering key information that can be utilised for protected area management, promoting sustainable tourism, and ensuring environmental preservation.

ARTICLE HISTORY
Received 6 November 2024
Accepted 9 June 2025

KEYWORDS
Mobile fitness apps; protected areas; big data; visitor's behaviour; recreational activities

Introduction

Protected areas, defined as geographical spaces dedicated to long-term nature conservation (Dudley, 2008), are vital for both society and our planet. They ensure environmental protection and provide essential socioeconomic and health benefits to local communities, as well as to tourists who visit for leisure and outdoor recreation (Carrus et al., 2015; Stolton & Dudley, 2010; Watson et al., 2014). However, their sustainability relies on careful planning to mitigate negative environmental impacts that result from excessive human use, such as trampling, dispersal of invasive species, waste production, or soil degradation and erosion (Ballantyne & Pickering, 2015; Barros et al., 2015; Marion et al., 2016). Nowadays, with protected areas facing escalating pressure from the expansion of tourism-related activities (Morgan, 2023; National Park Service, 2024; Schägner et al., 2017), effective visitor management emerges as an essential challenge in ensuring their sustainability (Eagles, 2014; Newsome et al., 2012).

To enable protected areas' socioeconomic and health benefits without causing environmental damage, it's necessary to balance visitors' recreational use with ecosystem conservation (Beeco & Brown, 2013). Consequently, protected area managers need detailed visitor data to make informed decisions regarding infrastructure development, staff allocation, and conservation measures (Ankre et al., 2016; Cessford & Muhar, 2003). To gather this essential information, an effective visitor monitoring system is needed(Eagles, 2014). Visitor monitoring refers to the systematic collection, analysis, and interpretation of data to understand visitor numbers, behaviours, movements, preferences, and impacts on the environment and wildlife (Arnberger et al., 2005; Cessford & Muhar, 2003; Griffin et al., 2010; Newsome et al., 2012).

Though some questions can be addressed using conventional monitoring methods (*e.g.* interviews, surveys, field observations, or access permits), they have limitations, such as time consumption, high cost, and location-specific measurements (Cessford & Muhar,

CONTACT Jorge Costa jorge.costa1997@hotmail.com Department of Geography, Faculty of Arts and Humanities, University of Porto, Via Panorâmica s/n, 4150–564 Porto, Portugal; CEGOT, Faculty of Arts and Humanities, University of Porto, Via Panorâmica s/n, 4150–564 Porto, Portugal

2003). To address these limitations, novel monitoring methods are emerging (A. Barros et al., 2020; Marion et al., 2016; Pickering et al., 2011). One such developing approach is leveraging crowdsourced data (*i.e.* data collected from a large online community) from social-media and mobile apps (Barros et al., 2022; Ghermandi, 2022; Teles da Mota & Pickering, 2020). Results emerging from these digital technological approaches show positive correlations when compared with conventional monitoring methods and have numerous advantages in terms of cost-effectiveness, data accessibility, and the elimination of 'knowledge bias' (Barros et al., 2022; Ghermandi, 2022; Ghermandi & Sinclair, 2019; Norman & Pickering, 2017). However, there are some limitations in the use of crowdsourced data, such as sampling bias, user privacy, and about how social media and mobile apps share data with academic researchers (Barros et al., 2022; Norman et al., 2019; Norman & Pickering, 2019).

Social networks and mobile apps are fast-paced industries with fluctuating popularity, changing user bases that vary across different regions, and growing concerns about free data access (Ghermandi, 2022; Teles da Mota & Pickering, 2020; Wilkins et al., 2021). Any change in accessibility to crowdsourced data can negatively impact scientific production and threaten the loss of essential data (Ghermandi et al., 2022). To mitigate the impact of data access changes in specific platforms, such as those caused by the fast-paced evolutionary nature of the digital world or unexpected changes in data access rules, it's crucial to continually expand data sources that can be used in scientific research. Lately, researchers have started to use GPS tracking data (*i.e.* positional information obtained through GPS technology) from MFAs to study visitors' behaviour in protected areas (Campelo & Nogueira Mendes, 2016; Nogueira Mendes et al., 2012; Norman & Pickering, 2017). MFAs differ from other apps used to monitor visitors in protected areas, as they are capable of tracking their complete path during their visits, providing managers with detailed movement data to optimise conservation and visitor-management strategies (Sisneros-Kidd et al., 2021). Such apps are typically used by visitors to record and share outdoor activities (such as hiking, running, or cycling), offering a level of detail about their activities that exceeds other types of crowdsourced data (Barros et al., 2019; D'Antonio et al., 2022; Meijles et al., 2014).

Research leveraging GPS tracking data from MFAs to monitor visitors in protected areas is recent, but its application is increasing, with 17 papers being published in the last 5 years. Considering the importance of this theme and its novelty, a literature review is essential to clarify the underlying reasons behind the limited application of MFA-based monitoring. Furthermore, it would also be relevant to frame this subset of research against existing knowledge. This framing is especially important alongside studies leveraging big data to evaluate nature tourism (Teles da Mota & Pickering, 2020) in order to understand visitation in protected areas (Barros et al., 2022; Wilkins et al., 2021), and to evaluate the correlation between big data and visit counts in natural areas (Ghermandi, 2022). These studies did not adequately highlight content from MFAs, where 77% of the studies and 67% of the platforms analysed in the work presented here were not included in their literature considerations and underpinning. This paper seeks to address the following questions: (1) Who carries out the research? (2) Where is the research being conducted? (3) What are the main sources of knowledge? (4) What are the core research objectives? (5) What data sources are being used? (6) How is GPS tracking data being collected and validated?

Table 1. Search query approach used in SCOPUS and Web of Science.

Platform	Query
Web of Science (WOS)	TS = ('Geotagged' OR 'Georeferenced' OR 'Big data' OR 'Social media' OR 'Mobile App*' OR 'volunteered geographic information' OR 'Flickr' OR 'Wikiloc' OR 'Strava' OR 'Panoramio' OR 'GPSies' OR 'AllTrails' OR 'Twitter' OR 'MapMyFitness' OR 'Instagram') AND TS = ('National Park*' OR 'Natural Area*' OR 'Natural Park*' OR 'Protected Area*' OR 'Protected Park*' OR 'Conservation area*' OR 'Conservation Park*' OR 'Nature Reserve*' OR 'Wildlife Refuge*' OR 'Marine Reserve*' OR 'Ecosystem services' OR 'Nature-based recreation' OR 'Nature-based tourism' OR 'Nature based recreation' OR 'Nature based tourism') AND English (Languages)
SCOPUS	TITLE-ABS-KEY('Georeferenced' OR 'Geotagged' OR 'Big data' OR 'Social media' OR 'Mobile App*' OR 'volunteered geographic information' OR 'Flickr' OR 'Wikiloc' OR 'Strava' OR 'Panoramio' OR 'GPSies' OR 'AllTrails' OR 'Twitter' OR 'MapMyFitness' OR 'Instagram') AND TITLE-ABS-KEY('National Park*' OR 'Natural Area*' OR 'Natural Park*' OR 'Protected Area*' OR 'Protected Park*' OR 'Conservation area*' OR 'Conservation Park*' OR 'Nature Reserve*' OR 'Wildlife Refuge*' OR 'Marine Reserve*' OR 'Ecosystem services' OR 'Nature-based recreation' OR 'Nature-based tourism' OR 'Nature based recreation' OR 'Nature based tourism') AND LANGUAGE(English)

Methodology

Search query

A comprehensive search was performed on SCOPUS and Web of Science (WOS) until the end of 2023. These databases were selected because they are cross-disciplinary and highly reputed database sources of scientific research (Harzing & Alakangas, 2016). Our approach followed the method for systematic quantitative literature reviews (Pickering et al., 2014; Pickering & Byrne, 2013) and PRISMA (Preferred Reporting Items for Systematic Review Recommendations) guidelines (Liberati et al., 2009; Moher et al., 2009).

The search queries used as inputs into the SCOPUS and WOS databases (Table 1) consisted of two lists of terms. One that focused on terms related to the data sources and types used, with the goal of capturing the technical and methodological aspects of the research. The second, aimed at capturing studies conducted in protected areas. The queries returned studies that included at least one term from each list in the title, abstract, or keywords.

Study selection

The search queries listed in Table 1 were used across the chosen databases, and the results were exported from SCOPUS (1079 publications) and WOS (912 publications) into a reference manager software. The first step of the systematic screening comprised the 'identification' and elimination of any duplicate studies. Accordingly, the publications' titles and abstracts were analysed in a first 'screening' step to eliminate any studies that were clearly unrelated to the scope of our literature review. Next, a further 'screening' step involved a thorough examination of the remaining publications analysing their full-text documents. Studies that did not use GPS tracking data from MFAs and studies that the study site didn't overlap with protected areas were excluded to ensure consistency. Although these criteria may introduce selection biases by overlooking studies with alternative methodologies or in different environments, they were necessary for achieving methodological consistency and meeting the research objectives. This step allowed us to select 'eligible' articles that were explicitly analysing visitor GPS tracking data from MFAs in protected areas. Finally, we then used these articles to examine their cited-listed references in more detail to identify any relevant studies absent from the selected databases. After completing the screening and eligibility process, 26 publications were deemed suitable for further analysis (Figure 1).

Data extraction and analysis

Using the selected 26 publications, we then undertook a data extraction process to capture key information. For data handling accuracy and reliability purposes, the extracted information was organised into a coding frame, where it was summarised and tabulated. This key process was conducted independently by two authors. These independently acquired results were then compared to minimise any potential errors, thereby improving the integrity of the data extraction process. Furthermore, to enhance the analysis, detailed reference data was used to conduct a thorough bibliometric analysis using 'Bibliometrix', an advanced R package (Aria & Cuccurullo, 2017).

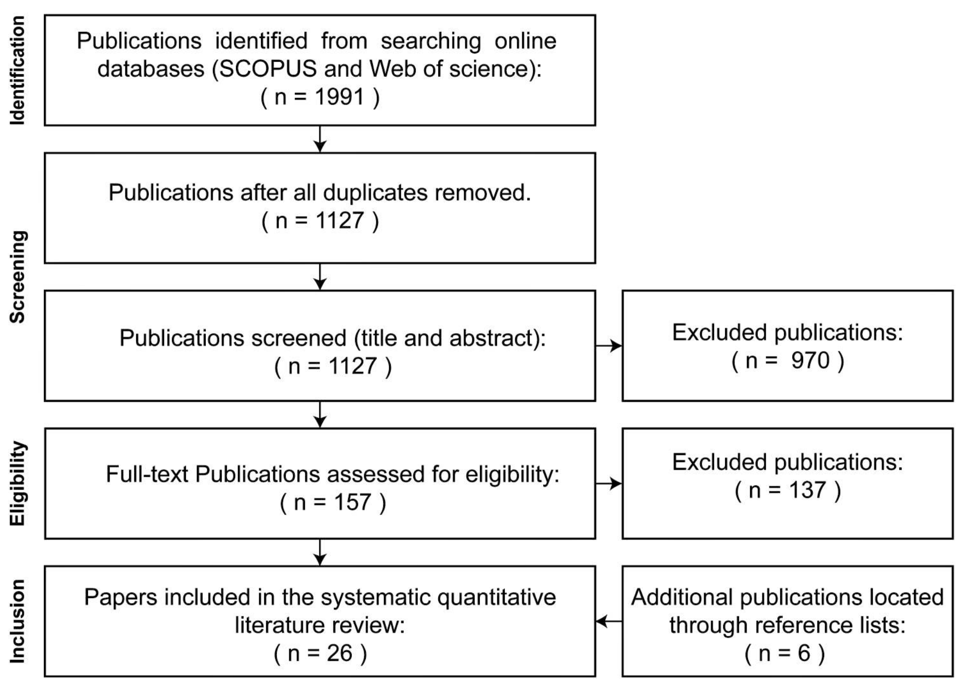

Figure 1. Flowchart of the literature review screening process and its quantitative outputs.

Results

When and where were the studies published?

From 2012 until 2023, 20 articles and 6 conference proceedings were published using GPS tracking data from MFAs in protected areas (Figure 2A). Publications on the topic started modestly (4 studies during 2012-16), subsequently increased (10 studies during 2017-21), and have recently experienced noteworthy acceleration (14 studies 2022-23). Overall, scientific production on this subject showed an annual growth rate of 19% from 2012 to 2023. Use of the 26 studies published from 2012–2023 is revealed in their citation patterns. Two studies published in 2023 received substantial interest, accumulating over ten citations within a year of their release (Horst et al., 2023; Smith et al., 2023).

Twelve journals have published on the GPS-MFAs topic (Figure 2B). The *Landscape and Urban Planning* and *Journal of Outdoor Recreation* are the main outlets, each having published four articles while the *Journal of Environmental Management* and *Applied Geography* are lesser used with 2 publications each. For the six conference proceedings published between 2012 and 2023, four were published in association with the International Conference on Monitoring and Management of Visitors in Recreational and Protected Areas. This highlights this specialist themed conference as a key platform for communicating research using GPS tracking data in monitoring protected area visitors.

Who carries out the research?

The analysed studies were written by 61 authors. Among them, four authors have three or more publications, while 48 have participated in only one study. The main authors in the field, based on their contribution

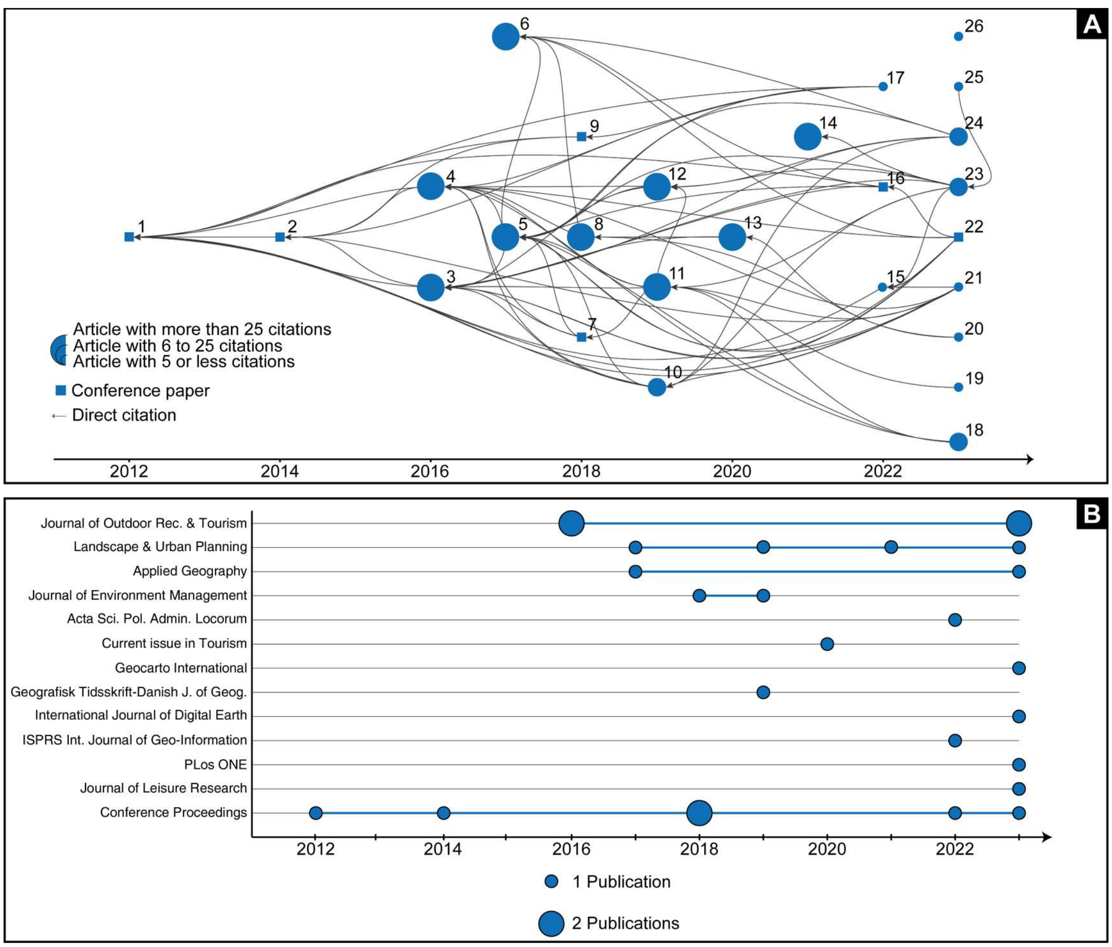

Figure 2. Main sources of knowledge: (A) Illustration showing the direct citation network and the articles impact. (B) Sources of the published studies. (1) Nogueira Mendes et al. (2012); (2) Nogueira Mendes et al. (2014); (3) Campelo and Nogueira Mendes (2016); (4) Santos et al. (2016); (5) Norman and Pickering (2017); (6) Korpilo et al. (2017); (7) Norman and Pickering (2018); (8) Korpilo et al. (2018); (9) Roque et al. (2018); (10) Rota, et al. (2019); (11) Norman and Pickering (2019); (12) Norman et al. (2019); (13) C. Barros et al. (2020); (14) Venter et al. (2021); (15) Santos et al. (2022); (16) Monteiro and Cabral (2022); (17) Ciesielski et al. (2022); (18) Schirck-Matthews et al. (2023);(19) Chai-Allah et al. (2023); (20) Dong et al. (2023); (21) Nogueira Mendes et al. (2023); (22) Monteiro and Cabral (2023); (23) Smith et al. (2023); (24) Horst et al. (2023); (25) Zhao and Wang (2023); (26) Che et al. (2023).

amount, are: (1) Nogueira Mendes (seven publications; three publications as first author); (2) Norman (five publications, four publications as first author); (3) Pickering (five publications); and (4) Silva (five publications). The authors that participated in the studies are mostly affiliated with Portuguese and Chinese institutions, with fourteen and thirteen authors, respectively (Figure 3). Additionally, other well-represented countries are Spain (eight authors), Australia, and Norway (five authors). Most researchers are affiliated with European institutions (69%), 13 authors are affiliated with Asian institutions, 5 are affiliated with institutions in Oceania, and 3 authors are affiliated with North American institutions. Authors from South American or African institutions are notably absent, revealing an unequal distribution in scientific production that appears to be related with MFAs data availability.

The author collaboration network is typically composed of many small clusters, each consisting of two to four authors (Figure 3). This pattern indicates that cooperative research generally takes place in isolated, limited-scale collaborations. An exception to this trend is a group consisting of thirteen individuals who collaborated on seven publications. Nogueira Mendes appears to be the lead author of the cluster, and its most robust partnership occurs with Silva (four publications). Additionally, the Australian cluster is also notable, since the connection between Pickering and Norman is the strongest in the entire network, collaborating on five publications. However, only four authors comprise this cluster.

Twenty-five institutions are evident from the collaboration network analysis (Figure 3). The most common affiliations are: (1) Lisbon Nova University (eight authors; nine publications); (2) Griffith University (four authors; five publications); and (3) University of Lisbon (five authors; four publications). The collaboration network consists of five isolated nodes and seven separate clusters. Among these clusters, only three possess international partnerships. The only cluster counter to this trend is the one between the Portuguese universities of the University of Lisbon, Lisbon Nova University, and the University of Aveiro, and the Spanish university of Lleida University. This cluster collaborated on nine publications, with the strongest network link between the University of Lisbon and Lisbon Nova University.

Where was the research conducted?

Portugal has the largest number of studies undertaken on protected areas (9 publications). However, eight of them focus on protected areas within the confines of the Lisbon metropolitan area (Figure 4). Australia ranks second with five studies focused within the Southeast-

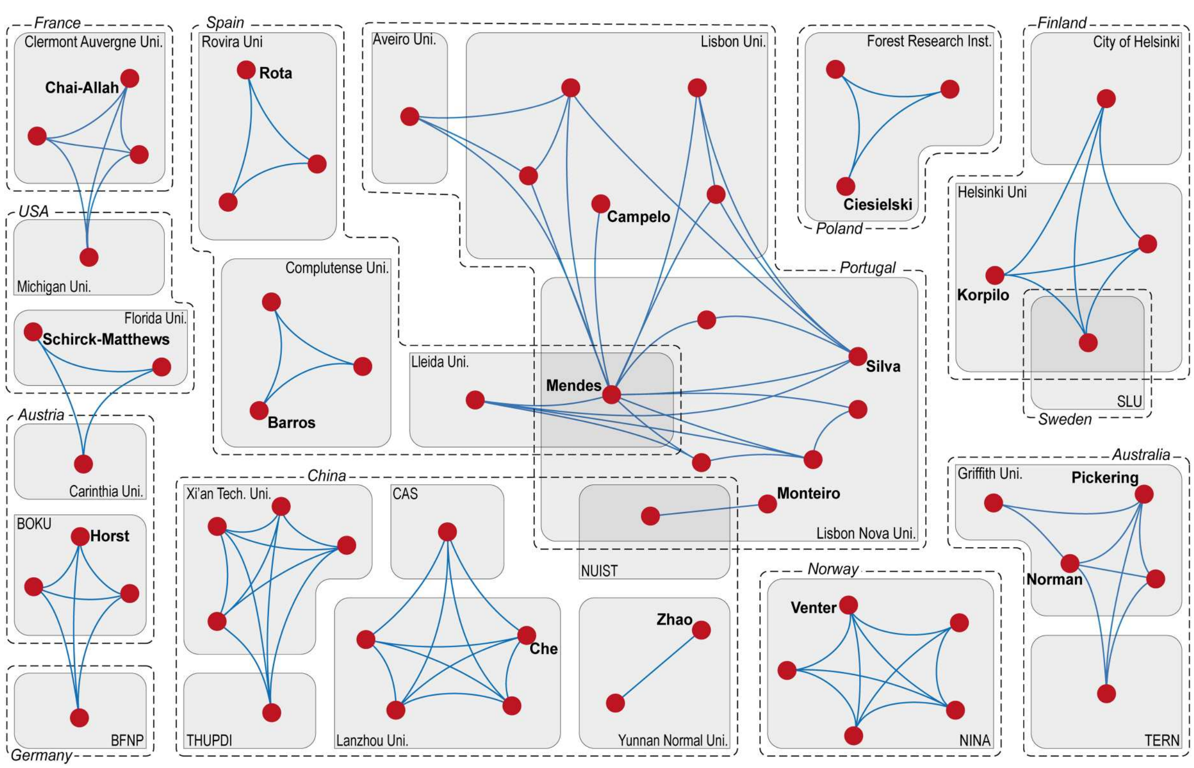

Figure 3. Collaboration network illustrating the linkages between authors, their institutional affiliations, and the institutions' country of origin.

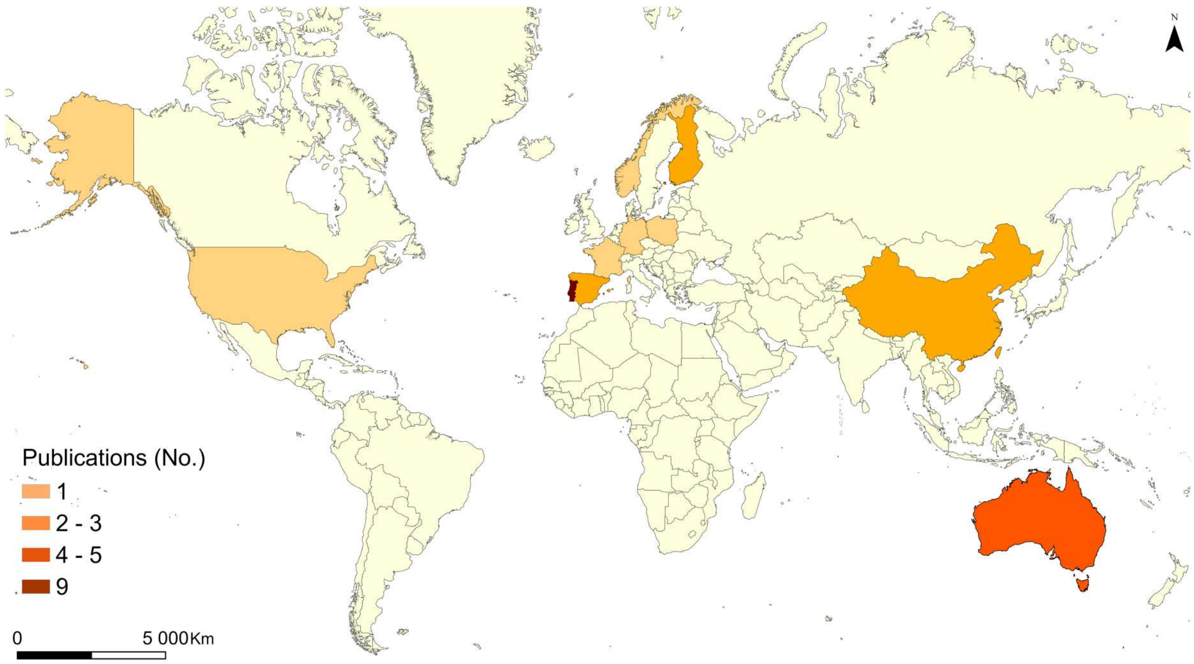

Figure 4. Number of studies conducted in each country's protected *areas*.

Queensland region. China has three studies in three different protected areas, all of them published in 2023. Finnish and Spanish protected areas have two studies each, and protected areas in Germany, France, Norway, and Poland only have one study each. There are no protected areas analysed in South America or Africa, and no studies analysing multiple protected areas across different countries.

Most cited references

The 26 selected studies cite a total of 906 publications (Figure 5). Only 5% of the cited publications were published before the 2000s, and 15% were published between 2000 and 2009. This means that research using GPS tracking data from MFAs in protected areas is mostly influenced by works published after 2010 (80%). Four publications from the selected studies are within the fifteen most cited references (Table 2). Among them, the most cited publication was the Campelo and Nogueira Mendes (2016) article with 13 citations, the Norman and Pickering (2017) article with 11 citations, and the Nogueira Mendes et al. (2012) and the Santos et al. (2016) publications with 10 citations. These four articles are amongst some of the first publications on this topic and are expected to be cited by subsequent studies to contextualise prior research on the subject (Figure 2A). The remaining studies focus on the role social media, Volunteered Geographical Information, and GPS technology (Beeco et al., 2014; D'Antonio et al., 2010; Goodchild, 2007; Heikinheimo et al., 2017; Orellana et al., 2012; Wolf et al., 2012; Wolf

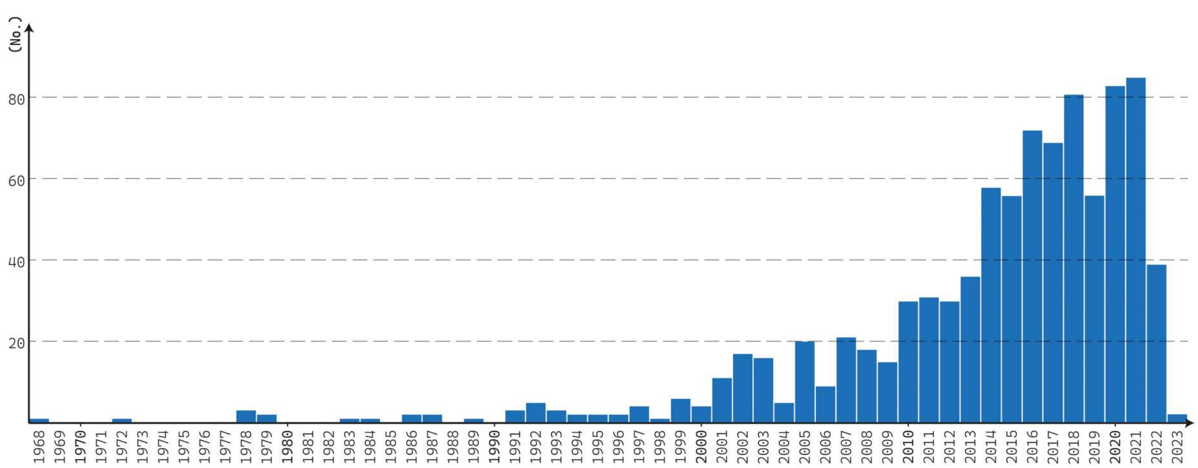

Figure 5. References cited in the analysed studies.

Table 2. Most cited references by the analysed studies.

Reference	Times cited (No.)
Campelo and Nogueira Mendes (2016)	13*
Norman and Pickering (2017)	11*
Wood et al. (2013)	10
Santos et al. (2016)	10*
Heikinheimo et al. (2017)	10
Nogueira Mendes et al. (2012)	10*
Wolf et al. (2015)	9
Cessford and Muhar (2003)	8
Goodchild (2007)	8
Beeco et al. (2014)	6
Hadwen et al. (2007)	6
Eagles (2014)	6
Orellana et al. (2012)	6
D'Antonio et al., (2010)	6
Wolf et al. (2012)	6

* Study included in this literature review.

et al., 2015; Wood et al., 2013); and on methods to monitor visitors (Cessford & Muhar, 2003; Hadwen et al., 2007).

What are the core research objectives?

The most common objective in the examined studies is the spatial analysis of user movements in protected areas (Table 3). Here, researchers focused on quantifying and differentiating use intensity (Korpilo et al., 2018; Norman & Pickering, 2017; Zhao & Wang, 2023), what types of circuits visitors preferred to do (Norman et al., 2019), and to analyse the relations between the location of major recreation hotspots and the trail network (Jurado Rota et al., 2019). Another aspect explored by researchers was the analysis of visitors' temporal patterns, aiming to understand differences in protected area visitation during workdays and the weekend (Ciesielski et al., 2022; Norman et al., 2019) and the differences in visitation at a monthly and seasonal level (Monteiro & Cabral, 2023; Nogueira Mendes et al., 2023; Roque et al., 2018). Validating the accuracy of MFAs data is a frequently cited objective mentioned in 8 publications; however, only 5 studies statistically compared MFAs data with on-site visitor data retrieved using conventional methods (Horst et al., 2023; Norman et al., 2019; Norman & Pickering, 2017; Smith et al., 2023; Venter et al., 2021).

Many studies compared distinct user groups and activities, comparing their behaviour inside protected areas (Korpilo et al., 2018; Santos et al., 2022; Zhao & Wang, 2023) and in examining spatial overlap and evaluating potential conflicts (Santos et al., 2022). Other studies focused on comparing protected areas and analysing their popularity, aiming to find the main factors (e.g. distance to urban centres, facility availability, ease of access) associated with the popularity of protected areas (Chai-Allah et al., 2023; Norman et al., 2019; Smith et al., 2023; Zhao & Wang, 2023). Six publications aimed to identify potential applications of GPS tracking data from MFAs in the management of protected areas. Three publications aimed to identify benefits

Table 3. Main objectives mentioned by the authors of the analysed publications.

Main Objectives	Number of Publications	Publications References
Spatialize users' movement	16	Campelo and Nogueira Mendes (2016); Korpilo et al. (2017); Korpilo et al. (2018); Rota, et al. (2019); Norman and Pickering (2019); C. Barros et al. (2020); Venter et al. (2021); Santos et al. (2022); Monteiro and Cabral (2022); Ciesielski et al. (2022); Dong et al. (2023); Nogueira Mendes et al. (2023); Monteiro and Cabral (2023); Horst et al. (2023); Zhao and Wang (2023); Che et al. (2023).
Analyse temporal patterns	7	Norman et al. (2019); C. Barros et al. (2020); Ciesielski et al. (2022); Dong et al. (2023); Nogueira Mendes et al. (2023); Monteiro and Cabral (2023); Zhao and Wang (2023).
Validate the accuracy of route data	8	Norman and Pickering (2017); Korpilo et al. (2017); Norman and Pickering (2018); Roque et al. (2018); Norman et al. (2019); Santos et al. (2022); Smith et al. (2023); Horst et al. (2023).
Compare data sources	4	Campelo and Nogueira Mendes (2016); Norman and Pickering (2017); Norman and Pickering (2018); Horst et al. (2023); Schirck-Matthews et al. (2023).
Compare users' activities	3	Rota, et al. (2019); Norman et al. (2019); Santos et al. (2022); Schirck-Matthews et al. (2023).
Compare different user groups	3	Santos et al. (2016); Korpilo et al. (2018); Venter et al. (2021).
Detect users' provenience	2	Roque et al. (2018); Santos et al. (2022).
Compare study areas	2	Norman and Pickering (2017); Norman and Pickering (2019).
Protected areas popularity analysis	5	Norman and Pickering (2019); Norman et al. (2019); Chai-Allah et al. (2023); Smith et al. (2023); Zhao and Wang (2023).
Analyse off/informal trail usage	6	Norman and Pickering (2017); Korpilo et al. (2017); Korpilo et al. (2018); Rota, et al. (2019); Monteiro and Cabral (2022); Monteiro and Cabral (2023).
Identify environmental impacts	2	Monteiro and Cabral (2022); Monteiro and Cabral (2023).
Identify potential and applications	6	Korpilo et al. (2017); Norman and Pickering (2018); Korpilo et al. (2018); Rota, et al. (2019); Barros et al. (2020); Monteiro and Cabral (2023).
Identify benefits and limitations	3	Korpilo et al. (2017); Norman and Pickering (2018); Norman et al. (2019).
Analyse COVID-19 effects	2	Venter et al. (2021); Smith et al. (2023).

and limitations of GPS tracking data, with the latest being published in 2019 (Norman et al., 2019).

The identification of environmental impacts and informal path analysis are a further common research objective mentioned in the previous studies. Specifically, studies aiming to analyse informal path use treated this issue as a relevant and possibly degradational environmental issue (Korpilo et al., 2018; Monteiro & Cabral, 2022; Monteiro & Cabral, 2023; Norman & Pickering, 2017). Lately, the analysis of the COVID-19 pandemic impact on protected area visitation was explored in two studies, with the studies exploring how protected area use changed during the pandemic phases or with different regulations.

What data sources were used?

Twelve different platforms were utilised in the analysed studies (Table 4). The most used platforms were AllTrails (www.alltrails.com) and Wikiloc (www.wikiloc.com) with eleven publications, followed by MapMyFitness (www.mapmyfitness.com) and Strava (www.strava.com) with four publications, while 2bulu (www.2bulu.com) was used in three publications. Seven out of twelve platforms were used for the first time after 2022. MapMyFitness, was used exclusively in Australia, and 2bulu exclusively in China. Only 40% of the publications drew data from multiple sources. From 2012 to 2015, AllTrails was the only platform used; between 2016 and 2019, some 60% of the publications used multiple data sources. After 2020, the number of publications using multiple data sources decreased to 31%.

Table 4. Data sources used in the publications.

Data Sources	References
AllTrails	Nogueira Mendes et al. (2012); Nogueira Mendes et al. (2014); Campelo and Nogueira Mendes (2016); Santos et al. (2016); Norman and Pickering (2017)**; Norman and Pickering (2018); Roque et al. (2018); Santos et al. (2022); Ciesielski et al. (2022); Horst et al. (2023); Nogueira Mendes et al. (2023); (Schirck-Matthews et al., 2023).
Wikiloc	Campelo and Nogueira Mendes (2016); Norman and Pickering (2017)**; Norman and Pickering (2018); Rota, et al. (2019); Barros et al. (2020); Norman et al. (2019)**; Monteiro and Cabral (2022); (18) Chai-Allah et al. (2023); Monteiro and Cabral (2023); Smith et al. (2023)**; (Schirck-Matthews et al., 2023).
MapMyFitness	Norman and Pickering (2017)**; Norman and Pickering (2018); Norman and Pickering (2019); Norman et al. (2019)**; Schirck-Matthews et al. (2023).
Strava	Korpilo et al. (2017); Norman and Pickering (2018); Norman et al. (2019)**; Venter et al. (2021)**.
Sports Tracker	Korpilo et al. (2017).
Endomondo	Ciesielski et al. (2022).
MapMyRide	Ciesielski et al. (2022).
2bulu	Dong et al. (2023); Zhao and Wang (2023); Che et al. (2023).
foooooot.com	Dong et al. (2023).
Outdooractive	Horst et al. (2023)**.
Komoot	Horst et al. (2023);
Trailforks	Smith et al. (2023)**.
Not specified *	Korpilo et al. (2017); Korpilo et al. (2018).

* Korpilo et al. (2017) and Korpilo et al. (2018) utilised data submitted by the public from MFAs but did not disclose all the source platforms. ** Studies that correlated the results with field counts.

What methods were used?

Twelve studies did not indicate their data collection process, while four studies used web scraping techniques, and four reported that the download of the data was done manually (Table 5). Three studies indicated that the data was collected automatically without specifying what techniques were employed, and two publications utilised online surveys that allowed users to submit routes done using MFAs to acquire the data. Venter et al. (2021) collected the data automatically using the Strava Metro platform, which returned the number of routes per OpenStreetMap segment.

The most frequently retrieved type of information was GPS routes, which were used in 22 studies. Nine studies collected metadata (*e.g.* activity realised, user nationality) associated with the routes, while two gathered data on the number of routes within each protected area. Venter et al. (2021) specifically gathered data on the number of routes per OpenStreetMap segment. Additionally, three studies collected information about users: Roque et al. (2018) identified the Wikiloc users' nationality through an analysis of their Wikiloc profiles. Korpilo et al. (2017) and Korpilo et al. (2018) complemented the GPS routes with socio-demographic data using a survey.

Five out of twenty-five studies (Table 6) analysed the correlation between mobile application data and on-site visitor data in protected areas (Horst et al., 2023; Norman et al., 2019; Norman & Pickering, 2017; Smith et al., 2023; Venter et al., 2021). Four of them used Pearson correlation to compare GPS tracking data with automatic counters data, while Horst et al. (2023) applied Spearman's correlation test. Three of the five studies that validated GPS tracking data from MFAs were conducted in Australia.

Norman and Pickering (2017) validated their MapMyFitness results concerning visitors in Australian protected areas. The linear regression analysis results returned statistically significant R^2 values ranging from 0.588 for walking to 0.864 for running, implying different levels of predictive accuracy depending on which activity is selected to analyse the park's popularity. In a subsequent study, Norman et al. (2019) found that running exhibited the highest R^2 value, while mountain biking had the lowest. Only the analysis for running was statistically significant. Venter et al. (2021) found

Table 5. Types of information retrieved, download and validation methods employed in the reviewed studies.

Reference	Data download	Sample size	Information retrieved	Validation method
Nogueira Mendes et al. (2012)	Not specified	338 tracks	GPS routes	None
Nogueira Mendes et al. (2014)	Not specified	2432 tracks	GPS routes	None
Campelo and Nogueira Mendes (2016)	Not specified	631 tracks	GPS routes	None
Santos et al. (2016)	Not specified	342 tracks	GPS routes	None
Norman and Pickering (2017)	Manual	1398 tracks	GPS routes	Pearson correlation
Korpilo et al. (2017)	Survey	55 tracks	GPS routes; Users' information	None
Norman and Pickering (2018)	Not specified	>8500 tracks	GPS routes	None
Korpilo et al. (2018)	Survey	139 tracks	GPS routes; Users' information	None
Roque et al. (2018)	Not specified	32787 tracks	GPS routes; Users' information	None
Rota, et al. (2019)	Web Scrapping	5323 tracks	GPS routes; Route metadata	None
Norman and Pickering (2019)	Manual	948 tracks	Route no. per Protected Area	None
Norman et al. (2019)	Not specified	457176 tracks	GPS routes; Route metadata	Pearson correlation
C. Barros et al. (2020)	Manual	5064 tracks	GPS routes	None
Venter et al. (2021)	Automated	Not specified	Route no. per OSM segment; Route metadata	Pearson correlation
Santos et al. (2022)	Not specified	22031 tracks	GPS routes; Route metadata	None
Monteiro and Cabral (2022)	Web Scrapping	2195 tracks	GPS routes; Route metadata	None
Ciesielski et al. (2022)	Not specified	15220 tracks	GPS routes	None
Chai-Allah et al. (2023)	Automated	782 tracks	GPS routes	None
Dong et al. (2023)	Not specified	482 tracks	GPS routes	None
Nogueira Mendes et al. (2023)	Not specified	9523 tracks	GPS routes; Route metadata	None
Monteiro and Cabral (2023)	Web Scrapping	2495 tracks	GPS routes	None
Smith et al. (2023)	Manual	97768 tracks	Route no. per Protected Area	Pearson correlation
Schirck-Matthews et al. (2023)	Automated	18 248	GPS routes starting point	None
Horst et al. (2023)	Automated	1742 tracks	GPS routes; Route metadata	Spearman correlation
Zhao and Wang (2023)	Web Scrapping	3363 tracks	GPS routes; Route metadata	None
Che et al. (2023)	Not specified	1554 tracks	GPS routes; Route metadata	None

that Strava data showed higher correlations when comparing the number of visitors by month and week, but lower correlations when comparing daily visitor numbers.

Smith et al. (2023) used data from Trailforks and Wikiloc to validate the number of visitors in Australian protected areas, focusing on data from mountain biking and walking activities. The mountain biking data (collected from Trailforks) had an R^2 of 0.31 and the walking data (collected from Wikiloc) showed an R^2 of 0.45. In this case, both analyses demonstrated statistical significance. Horst et al. (2023) validated the walking data from AllTrails and Outdooractive using Spearman's correlation. In this study, the results from the AllTrails data revealed a significant correlation, while the Outdooractive data did not. Overall, GPS tracking data from MFAs provided significant and accurate results for running activities, while mountain biking data generally showed weaker correlations.

Discussion

Our analysis of the MFAs-protected area literature reveals the emerging state of this research topic, characterised by limited interconnections between institutions and countries and an increase in scientific production and collaborative efforts. The increase in scientific production appears to be closely associated with the

Table 6. Results from the validations made in the reviewed studies.

Reference	Data source	Activity	Validation method	Result	P-value	Dataset size
Norman and Pickering (2017)	MapMyFitness	All data	Person correlation	$R^2 = 0.803$	$P = 0.006$	1080 tracks
		Running	Person correlation	$R^2 = 0.864$	$P = 0.002$	483 tracks
		Walking	Person correlation	$R^2 = 0.588$	$P = 0.044$	597 tracks
Norman et al. (2019)	MapMyFitness	All data	Person correlation	$R^2 = 0.681$	$P < 0.001$	948 tracks
		Running	Person correlation	$R^2 = 0.836$	$P < 0.001$	226 tracks
		Walking	Person correlation	$R^2 = 0.457$	$P = 0.032$	254 tracks
		Mountain biking	Person correlation	$R^2 = 0.284$	$P = 0.091$	468 tracks
Venter et al. (2021)	Strava	All data	Person correlation	$R^2 = 0.8$* $R^2 = 0.67$** $R^2 = 0.14$***	Not provided	Not provided
Smith et al. (2023)	Trailforks	Mountain biking	Person correlation	$R^2 = 0.31$	$P = 0.001$	~25000 tracks
	Wikiloc	Hiking	Person correlation	$R^2 = 0.45$	$P < 0.001$	~850 tracks
Horst et al. (2023)	AllTrails	Hiking	Spearman correlation	$\rho = 0.633$*	$P = 0.037$	402 tracks
	Outdooractive	Hiking	Spearman correlation	$\rho = 0.261$	$P = 0.438$	250 tracks

* Monthly time series; ** Weekly time series; *** Daily time series.

advent of new platforms providing GPS tracking data, such as 2bulo, Outdooractive, and Komoot. The availability of data also appears to be a significant driver behind the high number of publications originating from Portugal and Spain. These countries benefit from a substantial volume of data available from platforms like Wikiloc, which host approximately 50% of the 54 million routes on the Iberian Peninsula (www.wikiloc.com).

From a global perspective, the accessibility and abundance of data from MFAs appear to substantially influence the geographical distribution of studies and the affiliations of the researchers involved. Although the geographical distribution of studies is restricted to a low number of countries and regions, the studies have good global coverage and at the very least provide a solid base for future research. Furthermore, at a more local level, the country specific studies provide valuable insights that can address country or region-specific conservation issues. The geographical concentration of studies also highlights where knowledge gaps exist. This creates opportunities for future research to explore and address the unique challenges and conservation needs in under-represented regions such as Africa and South America. The global expansion of MFA-based monitoring is currently underway, as evidenced by the appearance of recent studies from China and North America. However, it still needs to be expanded into under-represented regions. As global efforts to achieve the UN Sustainable Development Goals increasingly emphasise the importance of biodiversity, global conservation strategies, such as the Kunming-Montreal Global Biodiversity Framework, have emerged to guide conservation priorities (GBF, 2024; UNEP-WCMC & IUCN, 2024). Given the significance of such strategies, emerging monitoring methods are essential to ensure that the growing number of protected areas are effectively managed. In particular, MFA-based monitoring has the potential to support the effective management of protected areas by offering detailed insights into visitors' spatiotemporal behaviour.

Overall, data accessibility plays a significant role in knowledge production and influences where knowledge is created and applied. It also appears to influence the number of studies published. Most platforms do not offer APIs (Application Programming Interface) or an alternative method for collecting all the data simultaneously, thereby requiring researchers to possess advanced programming skills to automate data collection or to manually download the required data (a process that is exceedingly time-consuming). Given this impact, social media and MFAs data should be reconsidered as a free public good and efforts should also be made to facilitate data access (Ghermandi et al., 2022).

MFAs as surrogate for visit counts

Although numerous studies used GPS tracking data from MFAs to analyse visitors' use of protected areas, only five have compared this data with on-site visitor counters (Horst et al., 2023; Norman et al., 2019; Norman & Pickering, 2017; Smith et al., 2023; Venter et al., 2021). Of these, three were conducted in Australia; one took place in Germany and another in Sweden. Overall, the studies found that GPS tracking data is correlated with on-site counts (Norman et al., 2019; Norman & Pickering, 2017), that monthly and weekly time series produced better correlation results than daily time series (Venter et al., 2021), and that the correlation results vary across different activities (Norman et al., 2019; Norman & Pickering, 2017; Smith et al., 2023). Such findings imply that MFA data may reliably complement traditional on-site counters, particularly for activities such as running and walking. It was observed that stronger correlations existed for running and walking, whereas mountain biking data often did not align well with on-site counts (Norman et al., 2019; Norman & Pickering, 2017; Smith et al., 2023). The difference in correlation strength can be related to the overall visitation of protected areas. For instance, if an area is more popular for hiking/running, the data from those activities may have a stronger correlation with on-site counts. Additionally, Norman and Pickering (2017) suggested that on-site counters do not provide comprehensive data on mountain biking activities because technical issues with automatic counters can result in missing data (Andersen et al., 2014; D'Antonio et al., 2010; Smith et al., 2023; Tenkanen et al., 2017), and the counters struggle to measure use for different activities, complicating the analysis of specific visitation patterns (Job et al., 2021; Smith et al., 2023).

MFAs data more effectively capture unauthorised activities than conventional methods, as visitors are not fully aware of the monitoring and don't change their behaviour (Cessford & Muhar, 2003; Heikinheimo et al., 2017; Norman et al., 2019). This enhanced capability not only demonstrates the theoretical potential of crowdsourced data to refine existing monitoring frameworks but also underscores its practical application for improving the management of protected areas. While current studies highlight the benefits and limitations of both GPS tracking data from mobile apps and on-site visitor counters, there is a clear need for more integrated approaches. Conventional monitoring approaches can be used to collect information that cannot be achieved using MFAs and to fine-tune the insights provided by GPS tracking data. For example, the detailed spatial patterns obtained from MFA data could be utilised to improve the placement of automated counters. This can also enhance existing monitoring frameworks, such as the Optimal Visitor Monitoring System, a comprehensive method for monitoring visitors to Protected Areas based on an optimised use of automatic counters (Farías-Torbidoni et al., 2022). Identifying the predominant spatial patterns of visitors accessing the protected area through each park entrance enables the evaluation of specific locations where visitation pressure is likely to be most intense. On the other hand, MFA-based monitoring can be used to expand the information about the visitors' spatiotemporal behaviour to the whole area of the park, reducing the monitoring cost, and to understand unauthorised activities. By combining these methods, researchers and park managers can gain a more comprehensive understanding of trail use, leading to better-informed decisions for park management and conservation efforts.

Evaluating benefits and limitations

The benefits (Figure 6) and limitations of GPS tracking data from MFAs have been considered in the analysed studies. The benefits suggest that data is low-cost, up-to-date, and can be sourced and processed rapidly (Campelo & Nogueira Mendes, 2016; Ciesielski et al., 2022; Korpilo et al., 2018; Norman & Pickering, 2017; Norman & Pickering, 2018; Santos et al., 2022). Furthermore, the amount of data that can be collected underscores another significant advantage by providing a broader base for analytical insights (Ciesielski et al., 2022; Santos et al., 2022). MFAs data is also capable of reflecting temporal differences in the protected areas' use and popularity. For example, it can highlight changes to permitted activities or the closure of popular tracks, offering invaluable feedback on visitor behaviour (Smith et al., 2023). Additionally, with the growing accessibility and popularity of such data sources, there is potential to conduct visitors' spatiotemporal behaviour analysis within smaller regions, enabling researchers and stakeholders to analyse and report on it more quickly (Horst et al., 2023). GPS tracking data also provides results with high spatial and temporal resolution that have shown potential to support land management policies, decision-making processes, and a deeper understanding of the impacts of recreational activities on nature protection and restauration (C. Barros et al., 2020; Korpilo et al., 2017; Norman et al., 2019; Santos et al., 2022; Venter et al., 2021).

GPS tracking data also presents challenges and limitations that must be considered. Firstly, the activities posted on various platforms represent only a fraction of actual recreational use, potentially leading to skewed interpretations of data (Horst et al., 2023; Norman & Pickering, 2017). The accessibility of such data also varies significantly across different platforms, complicating its acquisition for research and management purposes (Ciesielski et al., 2022; Norman & Pickering, 2018; Smith et al., 2023; Venter et al., 2021). The quality of the data is hard to measure, and the strength of the GPS signal could potentially compromise the accuracy of GPS-based tracking (Horst et al., 2023; Korpilo et al., 2018). Data availability is subject to unpredictable platform policy changes, which can restrict or change access over time (Ciesielski et al., 2022). The popularity of web sharing platforms and social media changes over time, impacting the consistency and reliability of the data (C. Barros et al., 2020; Norman &

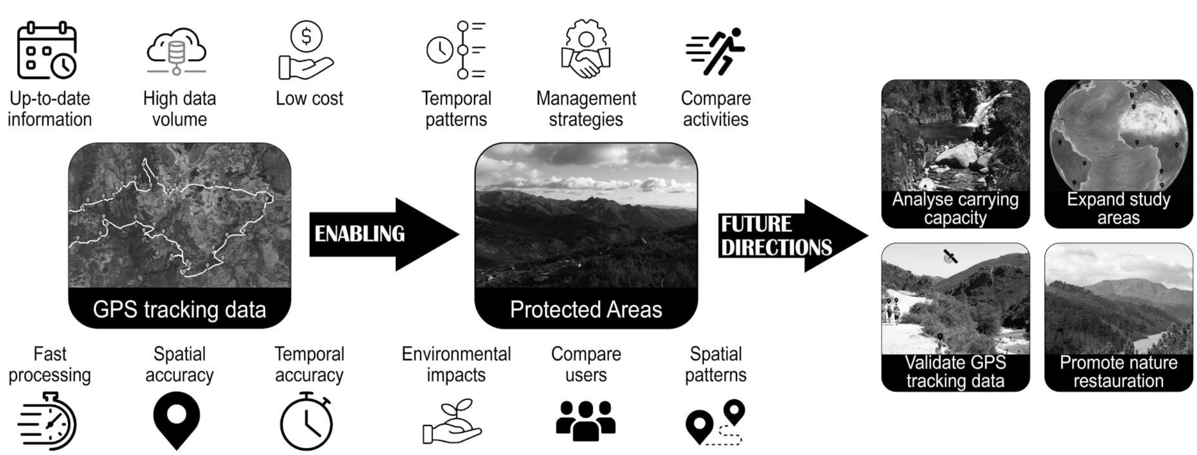

Figure 6. Illustration of the benefits of crowdsourced GPS tracking data, the most common applications in studies about the recreation in protected areas, and future directions identified by the authors through this literature review.

Pickering, 2018; Norman & Pickering, 2019; Smith et al., 2023). There are also notable differences in the type and volume of data provided by each platform (Norman & Pickering, 2017; Norman & Pickering, 2018; Smith et al., 2023). Regarding user-related factors, the data may be affected due to the overrepresentation of user groups (C. Barros et al., 2020; Norman & Pickering, 2017, 2019; Norman & Pickering, 2018; Venter et al., 2021). Additionally, there are important privacy concerns that should be considered when using data from online platforms, as the availability of data on public platforms does not automatically imply that users give their consent for its use in research (Ciesielski et al., 2022; Horst et al., 2023; Norman & Pickering, 2018). To address such privacy concerns, researchers and stakeholders should critically examine ethical implications related to user content, review the privacy policies provided by the MFAs, ensure that data is completely anonymised before analysis and, where feasible, obtain informed consent from MFAs users. Also, researchers and stakeholders must be aware of the regulatory policies and data ownership, as it can change among platforms and can restrict the way MFA data is retrieved and shared.

Research impact in protected areas management

GPS tracking data from MFAs may assist tourism management due to the large amount of reliable visitor data (Figure 6). Other methods of collecting GPS data (e.g. D'Antonio et al., 2010; Orellana et al., 2012) often result in visitors being aware their movement is being recorded, which may lead to altered behaviour, particularly when engaging in activities they perceive as inappropriate (Norman & Pickering, 2017). The absence of such bias in MFAs data makes it an excellent tool for visitor monitoring. It can be used to analyse visitors' spatial patterns (Campelo & Nogueira Mendes, 2016; Jurado Rota et al., 2019; Korpilo et al., 2017; Korpilo et al., 2018; Norman & Pickering, 2019; C. Barros et al., 2020; Che et al., 2023; Ciesielski et al., 2022; Dong et al., 2023; Horst et al., 2023; Monteiro & Cabral, 2022; Monteiro & Cabral, 2023; Nogueira Mendes et al., 2023; Santos et al., 2022; Venter et al., 2021; Zhao & Wang, 2023). It can also identify visitors' temporal patterns at different timescales (Norman et al., 2019; C. Barros et al., 2020; Ciesielski et al., 2022; Dong et al., 2023; Monteiro & Cabral, 2023; Nogueira Mendes et al., 2023; Zhao & Wang, 2023). The capacity to evaluate visitor temporal patterns and identify areas of increased activity within a park has several practical implications, including the optimisation of staff allocation and the development of essential infrastructure. Furthermore, it can evaluate protected areas' popularity (Chai-Allah et al., 2023; Norman et al., 2019; Norman & Pickering, 2019; Smith et al., 2023; Zhao & Wang, 2023). One of the most significant contributions is their application in assessing environmental impacts, including differentiating between formal and informal trail usage and evaluating landscape fragmentation (Jurado Rota et al., 2019; Korpilo et al., 2017; Korpilo et al., 2018; Monteiro & Cabral, 2022; Monteiro & Cabral, 2023; Norman & Pickering, 2017). In this context, MFAs can be employed to identify precise locations where visitors deviate from designated paths, facilitating targeted interventions to mitigate these behaviours, such as installing warning signs or blocking access. For instance, MFA data were utilised to identify the use of informal paths within Helsinki Central Park, which encompasses the Haltialanmetsä Nature Reserve. The specific issues identified in this study were subsequently addressed in the Central Park nature management plan (Korpilo et al., 2018). It can also be used to support facility development and staff allocation (C. Barros et al., 2020), to compare users' behaviour and identify potential conflicts (Korpilo et al., 2018; Santos et al., 2022; Zhao & Wang, 2023). More recently, it showed potential to access visitation changes after the COVID-19 outbreak (Smith et al., 2023; Venter et al., 2021). As previously discussed by Teles da Mota & Pickering (2019), social media and MFAs data can be collected retrospectively and address emerging issues in real time, making it highly valuable in analysing unexpected events that affect tourism in protected areas.

In comparison with other platforms (*e.g.* Instagram, Twitter), MFAs data is not capable of supporting studies about visitors' perceptions and sentiment analysis. But some platforms (*e.g.* Wikiloc, AllTrails) provide high amounts of photography data that can be used to analyse passive tourism, estimate economic values, and explore implications for ecosystem management (Teles da Mota, 2019). In addition to offering insights into visitor behaviours and movement patterns, MFAs data complements other forms of visitor monitoring. Overall, this research illustrates that employing this novel approach significantly enhances both theoretical understanding and practical management of visitors in protected areas. It demonstrates that MFAs is a visitation proxy that can support visitor monitoring and uncover detailed insights into visitor behaviour and environmental risks. Practically, the data provides essential information that helps protected area managers, stakeholders, and policymakers make well-informed decisions (Newsome et al., 2012), thereby enhancing visitor experiences, promoting sustainable tourism practices, and improving overall management strategies (Dong et al., 2023; Stamberger et al., 2018).

Future studies

Exploring methodological approaches is an exciting research field, and findings from this literature review suggest that more studies will be published on this topic in the coming years. Future studies should keep the focus on the validation of GPS tracking data as a reliable visitation proxy. Although five of the studies already compared GPS tracking data against values from on-site counters (Horst et al., 2023; Norman et al., 2019; Norman & Pickering, 2017; Smith et al., 2023; Venter et al., 2021), additional studies are still needed to ensure the global viability of GPS tracking data. Specifically, future research focusing on the validation of GPS tracking data should aim to: (1) evaluate MFAs data as a surrogate for on-site count sources in different areas of the world; (2) verify the capacity of MFAs as a proxy for visitation at smaller spatial and temporal scales; and (3) test the effectiveness between using multiple data sources versus individual data sources. While it is logical to assume that multiple sources would be more representative of the overall population, none of the reviewed studies tested whether using multiple data sources provided better results in terms of correlation with on-site counts.

A further important topic that should be explored is the potential of GPS tracking data to assess visitors' pressure within protected areas, to act as a dynamic indicator of carrying capacity (Barros et al., 2022), and their impact on nature protection. Nature and protected areas are an asset that needs to be expanded and effectively managed (Crofts et al., 2020; European Commission, 2021); this approach should not only be used to support policymakers, conservationists, and other stakeholders in managing and supporting informed within established protected areas. Additionally, it supports establishing new ones, promotes nature restoration and sustainable tourism, and ensures the conservation of key biodiversity and geodiversity areas.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This research received support from the Centre of Studies in Geography and Spatial Planning (CEGOT), funded by national funds through the Foundation for Science and Technology (FCT) under the reference UIDB/04084/2020; and Jorge Costa received support from the Foundation for Science and Technology (FCT) [grant number 2021.05304.BD].

Notes on contributors

Jorge Costa is a PhD student at the Faculty of Arts and Humanities of the University of Porto (Portugal) and a member of the CEGOT (Centre of Studies in Geography and Spatial Planning). His research focuses on the value of crowdsourced data in understanding visitors' behaviour patterns and managing outdoor recreation.

Alberto Gomes is an Associate Professor at the Faculty of Arts and Humanities of the University of Porto, in the Department of Geography, and a member of the CEGOT (Centre of Studies in Geography and Spatial Planning). He is a geoscientist whose research focuses on landscape development, natural hazards, and geoarchaeology. More recently, he is working on the sustainability of protected areas and the application of Big Data to environmental studies.

Martin Stokes is an Associate Professor at the University of Plymouth (UK). He is a geoscientist that research landscape development and natural hazards.

Miguel Saraiva is an Assistant Professor at the Faculty of Arts and Humanities of the University of Porto - Department of Geography, and a member of the scientific committee of CEGOT (Centre of Studies on Geography and Spatial Planning). He is an expert in modelling and analysing, using GIS tools, the relationships between urban morphology /design, and specific types of land-use and behaviour patterns, which he has applied, over the years, in various dimensions of urban, regional, accessibility and environmental planning.

ORCID

Jorge Costa http://orcid.org/0000-0001-9025-4829
Alberto Gomes http://orcid.org/0000-0002-1764-0659
Martin Stokes http://orcid.org/0000-0003-3788-4615
Miguel Saraiva http://orcid.org/0000-0001-5967-661X

References

Andersen, O., Gundersen, V., Wold, L. C., & Stange, E. (2014). Monitoring visitors to natural areas in wintertime: Issues in counter accuracy. *Journal of Sustainable Tourism*, *22*(4), 550–560. https://doi.org/10.1080/09669582.2013.839693

Ankre, R., Fredman, P., & Lindhagen, A. (2016). Managers' experiences of visitor monitoring in Swedish outdoor recreational areas. *Journal of Outdoor Recreation and Tourism*, *14*, 35–40. https://doi.org/10.1016/j.jort.2016.04.008

Aria, M., & Cuccurullo, C. (2017). Bibliometrix: An R-tool for comprehensive science mapping analysis. *Journal of Informetrics*, *11*(4), 959–975. https://doi.org/10.1016/j.joi.2017.08.007

Arnberger, A., Haider, W., & Brandenburg, C. (2005). Evaluating visitor-monitoring techniques: A comparison of counting and video observation data. *Environmental Management*, *36*(2), 317–327. https://doi.org/10.1007/s00267-004-8201-6

Ballantyne, M., & Pickering, C. M. (2015). The impacts of trail infrastructure on vegetation and soils: Current literature and future directions. *Journal of Environmental Management*, *164*, 53–64. https://doi.org/10.1016/j.jenvman.2015.08.032

Barros, A., Aschero, V., Mazzolari, A., Cavieres, L. A., & Pickering, C. M. (2020a). Going off trails: How dispersed visitor use affects alpine vegetation. *Journal of Environmental Management*, *267*, 1–11. https://doi.org/10.1016/j.jenvman.2020.110546

Barros, A., Pickering, C., & Gudes, O. (2015). Desktop analysis of potential impacts of visitor Use: A case study for the highest park in the southern hemisphere. *Journal of Environmental Management*, *150*, 179–195. https://doi.org/10.1016/j.jenvman.2014.11.004

Barros, C., Gutiérrez, J., & García-Palomares, J. (2022). Geotagged data from social media in visitor monitoring of protected areas; a scoping review. *Current Issues in Tourism*, *25*(9), 1399–1415. https://doi.org/10.1080/13683500.2021.1931053

Barros, C., Moya-Gómez, B., & García-Palomares, J. C. (2019). Identifying temporal patterns of visitors to national parks through geotagged photographs. *Sustainability*, *11*(24), 1–16. https://doi.org/10.3390/su11246983

Barros, C., Moya-Gómez, B., & Gutiérrez, J. (2020b). Using geotagged photographs and GPS tracks from social networks to analyse visitor behaviour in national parks. *Current Issues in Tourism*, *23*(10), 1291–1310. https://doi.org/10.1080/13683500.2019.1619674

Beeco, J. A., & Brown, G. (2013). Integrating space, spatial tools, and spatial analysis into the human dimensions Of parks and outdoor recreation. *Applied Geography*, *38*, 76–85. https://doi.org/10.1016/j.apgeog.2012.11.013

Beeco, J. A., Hallo, J. C., & Brownlee, M. T. J. (2014). GPS visitor tracking and recreation suitability mapping: Tools for understanding and managing visitor Use. *Landscape and Urban Planning*, *127*, 136–145. https://doi.org/10.1016/j.landurbplan.2014.04.002

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

Carrus, G., Scopelliti, M., Lafortezza, R., Colangelo, G., Ferrini, F., Salbitano, F., Agrimi, M., Portoghesi, L., Semenzato, P., & Sanesi, G. (2015). Go greener, feel better? The positive effects of biodiversity on the well-being of individuals visiting urban and peri-urban green areas. *Landscape and Urban Planning*, *134*, 221–228. https://doi.org/10.1016/j.landurbplan.2014.10.022

Cessford, G., & Muhar, A. (2003). Monitoring options for visitor numbers in national parks and natural areas. *Journal for Nature Conservation*, *11*(4), 240–250. https://doi.org/10.1078/1617-1381-00055

Chai-Allah, A., Fox, N., Brunschwig, G., Bimonte, S., & Joly, F. (2023). A trail-based approach using crowdsourced data to assess recreationists' preferences for landscape. *Landscape and Urban Planning*, *233*, 1–13. https://doi.org/10.1016/j.landurbplan.2023.104700

Che, M. L., Nian, Y. Y., Chen, S. W., Zhang, H., & Pei, T. (2023). Spatio-Temporal characteristics of human activities using location Big data in qilian mountain national park. *International Journal of Digital Earth*, *16*(1), 3794–3809. https://doi.org/10.1080/17538947.2023.2259926

Ciesielski, M., Dobrowolska, E., & Krok, G. (2022). Tourism and recreation in Polish national parks based on social media data. *Acta Scientiarum Polonorum, Administratio Locorum*, *21*(4), 513–528. https://doi.org/10.31648/aspal.7820

Crofts, R., Gordon, J. E., Brilha, J., Gray, M., Gunn, J., Larwood, J., Santucci, V. L., Tormey, D., & Worboys, G. L. (2020). Developing capacity for a protected planet. https://www.researchgate.net/publication/346259512_Guidelines_for_geoconservation_in_protected_and_conserved_areas.

D'Antonio, A., Monz, C. A., Crabb, B., Baggio, J. A., & Howe, P. D. (2022). Proof of concept study using GPS-based tracking data to build agent-based models of visitors' Off-trail behavior in nature-based tourism settings. *Applied Geography*, *147*, 1–11. https://doi.org/10.1016/j.apgeog.2022.102771

D'Antonio, A., Monz, C., Lawson, S., Newman, P., Pettebone, D., & Courtemanch, A. (2010). GPS-Based Measurements of backcountry visitors in parks and protected areas: Examples of methods and applications from three case studies. *Journal of Park & Recreation Administration*, *28*(3), 42–60. https://search.ebscohost.com/login.aspx?direct = true&AuthType = ip,shib,uid&db = asn&AN = 164694226&lang = pt-pt&site = ehost-live&scope = site.

Dong, W., Kang, Q., Wang, G. K., Zhang, B., & Liu, P. (2023). Spatiotemporal behavior pattern differentiation and preference identification of tourists from the perspective of ecotourism destination based on the tourism digital footprint data. *PLoS One*, *18*(4), 1–25. https://doi.org/10.1371/journal.pone.0285192

Dudley, N. (2008). *Guidelines for applying protected area management categories*. IUCN.

Eagles, P. F. J. (2014). Research priorities in park tourism. *Journal of Sustainable Tourism*, *22*(4), 528–549. https://doi.org/10.1080/09669582.2013.785554

European Commission (2021). *EU biodiversity strategy for 2030 – bringing nature back into our lives*. Publications Office of the European Union.

Farías-Torbidoni, E. I., Dorado, V., Morera, S., & Nogueira-Mendes, R. (2022). Optimizing the use of automatic counters to monitor visits to protected natural areas: The case study of montsant natural park, Spain. *Current Issues in Tourism*, *26*(20), 3348–3363. https://doi.org/10.1080/13683500.2022.2119551

Ghermandi, A. (2022). Geolocated social media data counts as a proxy for recreational visits in natural areas: A meta-analysis. *Journal of Environmental Management*, *317*, 1–9. https://doi.org/10.1016/j.jenvman.2022.115325

Ghermandi, A., & Sinclair, M. (2019). Passive crowdsourcing of social media in environmental research: A systematic Map. *Global Environmental Change*, *55*, 36–47. https://doi.org/10.1016/j.gloenvcha.2019.02.003

Ghermandi, A., Van Berkel, D., & Langemeyer, J. (2022). Twitter's totter must prompt research rethink. *Nature*, *612*(7939), 211. https://doi.org/10.1038/d41586-022-04362-4

Global Biodiversity Framework. (2024). Kunming-Montreal Global Biodiversity Framework. https://www.cbd.int/gbf.

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

Griffin, T., Moore, S., Crilley, G., Darcy, S., & Schweinsberg, S. (2010). Protected area management: Collection and use of visitor data volume 1: Summary and recommendations. Gold Coast, Queensland, Australia, Sustainable Tourism Cooperative Research Centre. https://researchportal.murdoch.edu.au/view/pdfCoverPage?instCode = 61MUN_INST&filePid = 13136922620007891&download = true.

Hadwen, W. L., Hill, W., & Pickering, C. M. (2007). Icons under threat: Why monitoring visitors and their ecological impacts in protected. *Areas Matters Ecological Management & Restoration*, *8*(3), 177–181. https://doi.org/10.1111/j.1442-8903.2007.00364.x

Harzing, A.-W., & Alakangas, S. (2016). Google scholar, scopus and the Web of science: A longitudinal and cross-disciplinary comparison. *Scientometrics*, *106*(2), 787–804. https://doi.org/10.1007/s11192-015-1798-9

Heikinheimo, V., Minin, E. D., Tenkanen, H., Hausmann, A., Erkkonen, J., & Toivonen, T. (2017). User-Generated geographic information for visitor monitoring in a national park: A comparison of social media data and visitor survey. *ISPRS International Journal of Geo-Information*, *6*(3), 1–14. https://doi.org/10.3390/ijgi6030085

Horst, L., Taczanowska, K., Porst, F., & Arnberger, A. (2023). Evaluation of gnss-based volunteered geographic information for assessing visitor spatial distribution within protected areas: A case study of the bavarian forest national park, Germany. *Applied Geography*, *150*, 1–13. https://doi.org/10.1016/j.apgeog.2022.102825

Job, H., Majewski, L., Engelbauer, M., Bittlingmaier, S., & Woltering, M. (2021). Establishing a standard for park visitation analyses: Insights from Germany. *Journal of Outdoor Recreation and Tourism*, *35*, 1–14. https://doi.org/10.1016/j.jort.2021.100404

Jurado Rota, J., Pérez Albert, M. Y., & Serrano Giné, D. (2019). Visitor monitoring in protected areas: An approach to natura 2000 sites using volunteered geographic information (VGI). *Geografisk Tidsskrift-Danish Journal of Geography*, *119*(1), 69–83. https://doi.org/10.1080/00167223.2019.1573409

Korpilo, S., Virtanen, T., & Lehvävirta, S. (2017). Smartphone GPS tracking—inexpensive and efficient data collection on recreational movement. *Landscape and Urban Planning*, *157*, 608–617. https://doi.org/10.1016/j.landurbplan.2016.08.005

Korpilo, S., Virtanen, T., Saukkonen, T., & Lehvävirta, S. (2018). More than A to B: Understanding and managing visitor spatial behaviour in urban forests using public participation GIS. *Journal of Environmental Management*, *207*, 124–133. https://doi.org/10.1016/j.jenvman.2017.11.020

Liberati, A., Altman, D. G., Tetzlaff, J., Mulrow, C., Gøtzsche, P. C., Ioannidis, J. P., Clarke, M., Devereaux, P. J., Kleijnen, J., & Moher, D. (2009). The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: Explanation and elaboration. *PLoS Medicine*, *6*(7), 1–28. https://doi.org/10.1371/journal.pmed.1000100

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

Meijles, E. W., de Bakker, M., Groote, P. D., & Barske, R. (2014). Analysing hiker movement patterns using Gps data: Implications for park management. *Computers, Environment and Urban Systems*, *47*, 44–57. https://doi.org/10.1016/j.compenvurbsys.2013.07.005

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred reporting items for systematic reviews and 0Meta-analyses: The prisma statement. *BMJ*, *339*(jul21 1), 1–8. https://doi.org/10.1136/bmj.b2535

Monteiro, L., & Cabral, P. (2022). The Use of volunteered geographic information to explore informal trail networks in protected areas. In C. Grueau, & L. Ragia (Eds.), *International conference on geographical information systems theory, applications and management* (pp. 86–101). SCITEPRESS. https://novaresearch.unl.pt/files/73693584/Volunteered_Geographic_Information_Explore_Informal_Trail_Networks_Protected_Areas.pdf

Monteiro, L., & Cabral, P. (2023). Assessing informal trails impacts and fragmentation effects on protected areas using volunteered geographic information. In C. Grueau, A. Rodrigues, & L. Ragia (Eds.), *Proceedings of the 8th International Conference on Geographical Information Systems Theory, Applications and Management (GISTAM 2022)*, (pp. 48–55). Scitepress. https://run.unl.pt/bitstream/10362/140174/1/Assessing_Informal_Trails_Impacts_and_Fragmentation_Effects_Protected_Areas_Volunteered_Geographic_Information.pdf

Morgan, R. (2023). *Annual Visits to NPWS Managed Parks in New South Wales*. https://www.environment.nsw.gov.au/-/media/OEH/Corporate-Site/Documents/Research/Our-science-and-research/annual-visits-npws-managed-parks-nsw-2022.pdf.

National Park Service. (2024). *Visitation numbers*. Retrieved July 3 from https://www.nps.gov/aboutus/visitation-numbers.htm.

Newsome, D., Moore, S. A., & Dowling, P. R. K. (2012). *Natural area tourism: Ecology, impacts and management*. Channel View Publications. https://books.google.pt/books?id=gwsenf9DisQC.

Nogueira Mendes, R., Dias, P., & Silva, C. P. (2014). Profiling MTB users' preferences within protected areas through webshare services. In M. Reimann, K. Sepp, E. Pärna, & R. Tuula (Eds.), *Proceedings of the 7th international conference on monitoring and management of visitors in recreational and protected areas, August* (pp. 20–23). Tallinn University, Institute of Health Sciences and Sports. https://mmv.boku.ac.at/refbase/files/2014-Mendes_et_al_Profiling_mtb_users.pdf

Nogueira Mendes, R., Farías-Torbidoni, E. I., & da Silva, C. P. (2023). Squeezing the most from volunteered geographic information to monitor mountain biking in peri-urban protected and recreational areas at a metropolitan scale. *Journal of Outdoor Recreation and Tourism*, *42*, 1–12. https://doi.org/10.1016/j.jort.2023.100624

Nogueira Mendes, R., Silva, A., Grilo, C., Rosalino, L. M., & Silva, C. (2012). MTB monitoring in arrábida natural park, Portugal. In P. Fredman, M. Stenseke, H. Liljendahl, A. Mossing, & D. Laven (Eds.), *Proceedings of the 6th international conference on monitoring and management of visitors in recreational and protected areas* (pp. 32–33). Forskningsprogrammet Friluftsliv i Förändring. https://mmv.boku.ac.at/refbase/files/mmv6_34_35.pdf

Norman, P., & Pickering, C. M. (2017). Using volunteered geographic information to assess park visitation: Comparing three online platforms. *Applied Geography*, *89*, 163–172. https://doi.org/10.1016/j.apgeog.2017.11.001

Norman, P., & Pickering, C. (2018). Using volunteered geographic information to assess the visitor use of parks. In *Proceedings of the 9th International Conference on Monitoring and Management of Visitors in Recreation, Bordeaux, France* (pp. 29-31). https://mmv.boku.ac.at/refbase/files/norman_patrick_pickering-2018-using-volonteered-geographic.pdf.

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*, 1–9. 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*, 180–190. https://doi.org/10.1016/j.landurbplan.2019.02.015

Orellana, D., Bregt, A. K., Ligtenberg, A., & Wachowicz, M. (2012). Exploring visitor movement patterns in natural recreational areas. *Tourism Management*, *33*(3), 672–682. https://doi.org/10.1016/j.tourman.2011.07.010

Pickering, C., & Byrne, J. (2013). The benefits of publishing systematic quantitative literature reviews for PhD candidates and other early-career researchers. *Higher Education Research & Development*, *33*(3), 534–548. https://doi.org/10.1080/07294360.2013.841651

Pickering, C., Grignon, J., Steven, R., Guitart, D., & Byrne, J. (2014). Publishing not perishing: How research students transition from novice to knowledgeable using systematic quantitative literature reviews. *Studies in Higher Education*, *40*(10), 1756–1769. https://doi.org/10.1080/03075079.2014.914907

Pickering, C. M., Rossi, S., & Barros, A. (2011). Assessing the impacts of mountain biking and hiking on subalpine grassland in Australia using an experimental protocol. *Journal of Environmental Management*, *92*(12), 3049–3057. https://doi.org/10.1016/j.jenvman.2011.07.016

Roque, B. F., Nogueira Mendes, R., Magalhães, M. F., & Pereira da Silva, C. (2018). Monitoring walkers and hikers of madeira island through web-share services. In *Proceedings of the 9th International Conference on Monitoring and Management of Visitors in Recreational and Protected Areas: Recreation, Place and Local Development, Bordeaux, France* (pp. 28-31). https://mmv.boku.ac.at/refbase/files/franco_roque_beatriz_nogueira_mendez-2018-monitoring-walkers-madeira.pdf.

Rota, J. J., Albert, M. Y. P., & Giné, D. S. (2019). Visitor monitoring in protected areas: An approach to natura 2000 sites using volunteered geographic information (VGI). *Geografisk Tidsskrift-Danish Journal of Geography*, *119*(1), 69–83. https://doi.org/10.1080/00167223.2019.1573409

Santos, T., Nogueira Mendes, R., Farias-Torbidoni, E. I., Juliao, R. P., & da Silva, C. P. (2022). Volunteered geographical information and recreational uses within metropolitan and rural contexts. *ISPRS International Journal of Geo-Information*, *11*(2), 1–22. https://doi.org/10.3390/ijgi11020144

Santos, T., Nogueira Mendes, R., & Vasco, A. (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

Schägner, J. P., Maes, J., Brander, L., Paracchini, M. L., Hartje, V., & Dubois, G. (2017). Monitoring recreation across European nature areas: A geo-database of visitor counts, a review of literature and a call for a visitor counting reporting standard. *Journal of Outdoor Recreation and Tourism*, *18*, 44–55. https://doi.org/10.1016/j.jort.2017.02.004

Schirck-Matthews, A., Hochmair, H., & Paulus, G. (2023). Comparison of reported outdoor activities in Florida state parks among three fitness tracker apps. *Journal of Leisure Research*, *54*(1), 46–71. https://doi.org/10.1080/00222216.2022.2153097

Sisneros-Kidd, A. M., D'Antonio, A., Monz, C., & Mitrovich, M. (2021). Improving understanding and management of the complex relationship between visitor motivations and spatial behaviors in parks and protected areas. *Journal of Environmental Management*, *280*, 1–13. https://doi.org/10.1016/j.jenvman.2020.111841

Smith, I., Velasquez, E., Norman, P., & Pickering, C. (2023). Effect of the COVID-19 pandemic on the popularity of protected areas for mountain biking and hiking in Australia: Insights from volunteered geographic information. *Journal of Outdoor Recreation and Tourism*, *41*, 1–12. https://doi.org/10.1016/j.jort.2022.100588

Stamberger, L., van Riper, C. J., Keller, R., Brownlee, M., & Rose, J. (2018). A Gps tracking study of recreationists in an alaskan protected area. *Applied Geography*, *93*, 92–102. https://doi.org/10.1016/j.apgeog.2018.02.011

Stolton, S., & Dudley, N. (2010). *Arguments for Protected Areas: Multiple Benefits for Conservation and Use*. Earthscan. https://books.google.com/books?hl = en&lr = &id = iMBVASWImIAC&oi = fnd&pg = PR5&ots = 5aDbHJSwT7&sig = dn1_O0uSVhFIAWxgGlLWgYfBkV0.

Teles da Mota, V., & Pickering, C. (2020). Using social media to assess nature-based tourism: Current research and future trends. *Journal of Outdoor Recreation and Tourism*, *30*, 1–11. https://doi.org/10.1016/j.jort.2020.100295

Tenkanen, H., Di Minin, E., Heikinheimo, V., Hausmann, A., Herbst, M., Kajala, L., & Toivonen, T. (2017). Instagram, Flickr, or twitter: Assessing the usability of social media data for visitor monitoring in protected areas. *Scientific Reports*, *7*(1), 1–11. https://doi.org/10.1038/s41598-017-18007-4

UNEP-WCMC & IUCN. (2024). Protected Planet Report 2024. UNEP-WCMC and IUCN: Cambridge, United Kingdom; Gland, Switzerland.

Venter, Z. S., Barton, D. N., Gundersen, V., Figari, H., & Nowell, M. S. (2021). Back to nature: Norwegians sustain increased recreational Use of urban green space months after the COVID-19 outbreak. *Landscape and Urban Planning*, *214*, 1–10. https://doi.org/10.1016/j.landurbplan.2021.104175

Watson, J. E. M., Dudley, N., Segan, D. B., & Hockings, M. (2014). The performance and potential of protected areas. *Nature*, *515*, 67–73. https://doi.org/10.1038/nature13947

Wilkins, E., Wood, S., & Smith, J. (2021). Uses and limitations of social media to inform visitor Use management in parks and protected areas: A systematic review. *Environmental Management*, *67*(1), 120–132. https://doi.org/10.1007/s00267-020-01373-7

Wolf, I. D., Hagenloh, G., & Croft, D. B. (2012). Visitor monitoring along roads and hiking trails: How to determine usage levels in tourist sites. *Tourism Management*, *33*(1), 16–28. https://doi.org/10.1016/j.tourman.2011.01.019

Wolf, I. D., Wohlfart, T., Brown, G., & 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

Wood, S. A., Guerry, A. D., Silver, J. M., & Lacayo, M. (2013). Using social media to quantify nature-based tourism and recreation. *Scientific Reports*, *3*(1), 1–7. https://doi.org/10.1038/srep02976

Zhao, O. Y., & Wang, J. X. (2023). Spatial-Temporal behaviour of hikers in the southeastern margin of qinghai-Tibet plateau: Insights from volunteered geographic information. *Geocarto International*, *38*(1), 1–22. https://doi.org/10.1080/10106049.2023.2296183