Assessing Informal Trails Impacts and Fragmentation Effects on Protected Areas using Volunteered Geographic Information

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Abstract: Informal trails represent an important visitor-related impact on the natural resources of recreational and protected areas by compacting soil, changing vegetation composition, moving wildlife, altering the hydrological cycle, and fragmenting landscapes. This paper develops an approach to assess the extent of the informal trails network and their trail-based impacts in a protected area within the Lisbon Metropolitan Area, Portugal. A total of 28.911,254 km of Volunteered Geographic Information tracks were collected from a fitness and travel web platform. Spatial analysis was performed to assess the extent of the informal infrastructure, and landscape metrics were used to understand the diversity of trail-based fragmentation across the area. A total of 669,6 km were mapped as potential informal trails, hiking being the most popular activity using this infrastructure. Approximately 58% of higher protection areas have been fragmented by informal trails development, representing a loss in the size and integrity of endangered habitat. The proposed approach allowed to produce a significant coverage of information about the levels of impact from informal trails at the landscape scale using a minimal amount of resources. Further work is recommended to validate results at the local scale using onsite trail-based assessments.

1 INTRODUCTION

Before the COVID-19 pandemic, many were concerned about the challenges relating to the management of overtourism in designated sites, and the increasing numbers of users engaging in outdoor activities in recreational and Protected Areas (PAs) (Atzori, 2020).

With the pandemic, many changes appeared at the society and individual level, and the outbreak showed again the importance of nature as a valuable asset for people to engage in outdoor activities when opportunities are limited and during stressful times (Jackson et al., 2021). During this period, as a result of the multiple instituted shutdowns orders, visitation levels reported worldwide registered a decline, especially in urban forest recreation sites where access was restricted, or in PAs located outside Metropolitan Areas, and overseas destinations due to restrictions on traveling (de Bie and Rose, 2021). In contrast, urban recreational and PAs that remained open and accessible continued to experience considerable levels of visitation, similar to the period of pre-COVID (Volenec et al, 2021).

An important reason for the high demand of visitors to touristic and recreational sites is the increased use of social media and the availability of volunteered geographic information (VGI) at specific websites (Chua et al., 2016; Goodchild, 2007). This is a consequence of the democratization of the technology, including the Global Positioning System (GPS) on mobile phones (Burke et al., 2006) and the increasing popularity of using applications to choose where and how to travel based on recommendations within social media networks and the trend to consume, create and share experiences on social media (Dickinson, Hibbert and Filimonau, 2016; Wang et al., 2014).

As a consequence of the reported numbers of users engaging in outdoor activities, that are often

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dependent on natural environments for their performance, significant impacts can appear in those areas that need to be assessed and managed. These impacts can carry several consequences, affecting ecosystem components; through the degradation of the soil, vegetation, water, and wildlife resources (Leung and Marion, 2000). This is particularly important on trail networks where recreational activities are performed most of the time (Marion and Leung, 2001).

Formal trail networks are important strategies to minimize recreationist impacts by concentrating use on appropriate walking surfaces (Marion and Leung, 2004). However, when these networks fail to provide the desired access and match the users´ experiences, often users tend to venture off-trail, leading to the creation of informal trails due to foot trampling (Wimpey and Marion, 2010). This type of impact can affect ecosystem components through the removal of vegetation, displacement of wildlife, alteration of hydrology, the spread of invasive species, and can also exacerbate ecological fragmentation effects in relatively undisturbed habitats (Walden-Schreiner et al, 2012; Wimpey and Marion, 2010).

Although informal trails are present in nearly all recreational areas and PAs, research focused on informal trail networks remains minimal. This may be due to the fact, that these user-created impacts are often materialized in numerous, short, and frequently segments arranged in complex patterns, making them difficult to assess (Leung and Marion, 1999).

Through the years, informal trails mapping and monitoring were commonly performed by using hand-held GPS units and covering the entire trail system networks of a site by walking (Wimpey and Marion, 2011). Since limited human and financial resources are often a major constraint, this technique is many times considered costly in terms of time and resources invested (Muhar, Arnberger and Brandenburg, 2002).

However, recently there is a growing interest in the use of new sources of data, such as VGI, to understand the spatial and temporal patterns of visitors' movements (Heikinheimo et al., 2017; Walden-Schreiner et al., 2018b; Wood et al., 2013). Among them, georeferenced tracks of users' routes from fitness and travel websites and apps are one of the most common components of VGI, as they provide information regarding the type of activity and related spatial and temporal aspects (Levin, Lechner and Brown, 2017; Orsi and Geneletti, 2013; Sessions et al., 2016). As this large number of VGI is many times available freely to the public, these data can also be used to reflect the spatial distribution of recreational use in informal trails, by comparing it with the existent formal infrastructures. Although, despite the apparent limitations on data quality and availability among sites, this type of information allows to make an assessment of the extent of the potential informal trail network within a recreational area in an effective, cheap, and accurate way (Norman and Pickering, 2017).

This paper presents a new approach that assesses how informal trails development can contribute to the fragmentation of recreational and PAs. Specifically, it will assess an informal trails network using geographic information systems (GIS) and VGI obtained from GPS routes from a fitness and travel platform to evaluate the lineal extent and variety of informal trails on the area, examine the spatial distribution of informal trails, and calculate the level of landscape fragmentation using appropriated metrics.

2 MATERIALS AND METHODS

2.1 Study Area

The proposed methodological approach was applied in the Arrábida Nature Park (PNAr), an important touristic and recreational destination located within Sesimbra, Azeitão, and Setúbal municipalities in Lisbon Metropolitan Area, which contains approximately 2,8 M inhabitants (Figure 1). Created in 1976 and being part of the National Network of Protected Areas, the PNAr has approximately 17.500 ha, including 5.200 of marine, and a maximum altitude of 501 m. It is dominated by one of the most original and interesting types of landscape in the country, with a wide variety of high-value ecosystems that were included in the Natura 2000 Network.

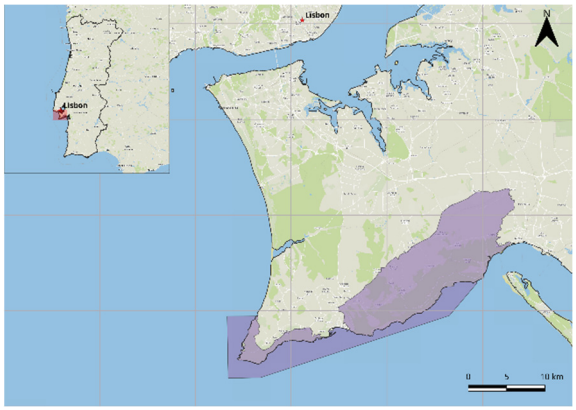

Figure 1: Location of Arrábida Nature Park in Portugal.

2.2 Methodology

The methodology was structured into three main phases: data collection from the Wikiloc.com website; spatial analysis of GPS routes using a GIS; and assessment of trail-based fragmentation using spatial metrics (Figure 2).

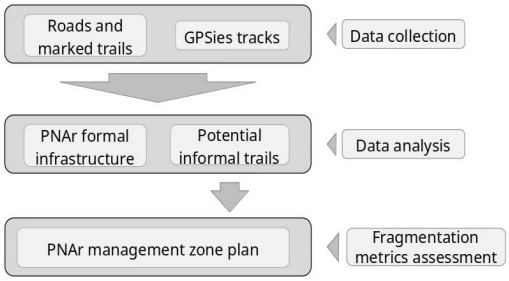

Figure 2: Schematic representation of the methodological approach.

2.2.1 Data Collection

In order to characterize the spatial distribution of visitor-created trails within the PNAr limits, the main dataset was collected from the Wikiloc website (Wikiloc, 2021), a crowdsourced online platform containing GPS routes from visitors who wanted to share their activities with others. For Europe, Wikiloc has at the moment one of the best data coverages and is considered to be suitable for off-trail use assessment (Campelo and Mendes, 2016; Norman and Pickering, 2017). The platform has operated since 2006, being one of the first fitness and travel websites, with more than 28 M tracks (672.000 for Portugal) and 9 M members by October 2021, allowing tracking using all kinds of GNSS devices and smartphones through dedicated applications for Android and IOS devices.

Search queries on Wikiloc were conducted on October 2021, using Setúbal, Sesimbra, and Palmela municipalities as search criteria and considering 30 activities that are using trails for their performance. Because Wikiloc limits the download to a few .gpx tracks per user/day, VGI data were downloaded using web scraping techniques.

In addition to the .gpx file, additional information associated with the routes was collected, such as author/user ID, URL of the track, route name/number, user description, date posted, date recorded, type of activity, route length, route type (linear or circular), and downloads received.

2.2.2 Spatial Analysis of GPS Routes

Duplicated tracks and those with evident spatial errors were eliminated unless the errors could be fixed. Also, as Wikiloc allows users to draw routes, these tracks were also excluded as they represent an intention of use and not an actual recording. The debugging process allowed create a clean shapefile with the entire downloaded GPS track using QGIS 3.10 (QGIS), and the park boundary polygon was used as a feature selection criteria for extracting the routes that crossed or were within the PANr limits to be used in the further analyses. One of the advantages of using QGIS with .gpx files is that it converts automatically the point data to line features without the need to run any data management tools.

For extracting the potential informal trail network, the official PNAr infrastructure (official public road network and marked trails), including official roads and trail network was considered as the formal trail network. Moreover, in order to absorb the spatial errors of bad GNSS reception under deficient atmospheric conditions and canopy cover, a 30 m buffer width of the formal PNAr infrastructure was created. The considered buffer width followed a similar procedure applied in the Campelo and Mendes (2016) study, but as satellite reception is sometimes reduced due to local characteristics of the area, the buffer width is a bit higher than the 10 metres employed by Korpilo et al., 2017 for example.

All tracks were then used and routes that intersected each PNAr infrastructure were extracted by selecting those that intersected the buffer polygons, and those that did not (selection, dissolve, and erase functions). The result was a shapefile compiling all GPS tracks from activities that used the formal roads and trail system and in opposite the potential informal trails, that will be used in the subsequent phase. The resulting trail networks were intersected with the PA zonation plan to summarize the linear extent of potential informal trails across different management zones. Additionally, the potential informal trails were also intersected with the slope map, according to different landform grade classes to understand if their development and spatial disposition are related to this aspect.

2.2.3 Trail-based Fragmentation Assessment

To assess the landscape fragmentation within the PNAr a method similar to Leung and Louie's (2008) and Wimpey and Marion (2011) was adopted. As such, both networks were considered to analyse the spatial impacts associated with the development of

informal trails within the PNAr, and to calculate different landscape metrics: Number of patches; Mean Patch Size; Largest Patch Index; Mean Perimeter: Area Ratio (Table 1). For the analysis, the complementary and partial management subcategories were merged into a single one of the same patch type.

Table 1: Landscape metrics.

Number of Patches (NP)	
Description	NP equals the number of patches of the corresponding patch type (class)
Units	None
Range	NP ≥ 1, without limit. NP = 1 when the landscape contains only 1 patch of the corresponding patch type.
Mean Patch Size (MPS)	
Description	MPS is the average patch size in a total class area
Units	m²
Range	NP ≥ 0, without limit
Largest Patch Index	
Description	LPI equals the area (m²) of the largest patch of the corresponding patch type divided by total landscape area (m²), multiplied by 100.
Units	Percentage (%)
Range	0 < LPI ≤ 100 LPI is close to 0 when the largest patch of the corresponding patch type is increasingly small. LPI = 100 when the entire landscape consists of a single patch of the corresponding patch type; meaning, the largest patch comprises 100% of the landscape.
Perimeter-Area Ratio	
Description	PAR equals the ratio of the patch perimeter (m) to area (m²).
Units	None
Range	PAR ≥ 0, without limit.

3 RESULTS

3.1 Extent of Use among Formal and Informal Infrastructure Networks

According to the considered search criteria, the final dataset downloaded from Wikiloc consisted of 3.923 individual tracks, representing a total accumulated of 28.911,254 km, with 2195 tracks (4.509,545 km) passing through the limits of the study area. This dataset was uploaded into the platform between March 2006 and October 2021 by 224 identified users that participated with 3.635 tracks of the total dataset downloaded and the remaining were anonymous.

Regarding the total length of use among each network, a total of 3.839,414 km were considered using the PNAr formal infrastructure and the remaining 669,586 km configured potential informal trails (Figure 3).

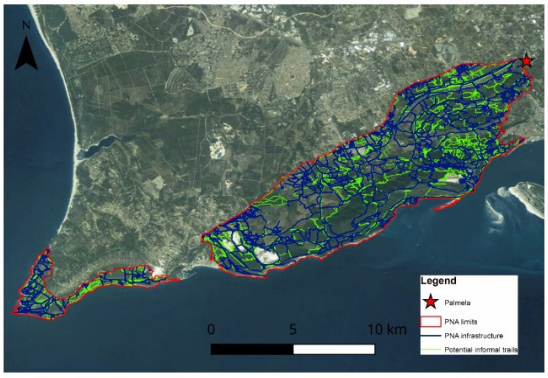

Figure 3: Spatial distribution of the formal infrastructure and potential informal trails.

From the routes downloaded from Wikiloc, that intersected the PNAr, 18% used the informal network (partially or entirely), and there were 21 routes that did not intersect a formal trail or road at any point. Of the 395 routes of users who travelled partially or entirely out of the formal infrastructure, 97 were cycling activities, 189 hiking, and 66 running. Only 32 informal trails were used by motorized vehicles and 11 routes recorded other activities (Table 2). A reclassification of Wikiloc activities was necessary following the mobility typology proposed by Callau, Giné and Perez (2020).

Table 2: Number of GPS tracks posted according to each type of activity along the formal and informal infrastructure.

Activity	On formal infrastrcture	On informal trails
Cycling	428	97
Hiking	977	189
Running	295	66
Motorized	311	32
Others	89	11

When plotting results against the PNAr management zonation plan, 66% of the potential informal network was developed on complementary protection, 27% on partial protection, and the remaining 7% on full protection (Figure 4). These results represent all potential management conflicts between current uses and each management zone.

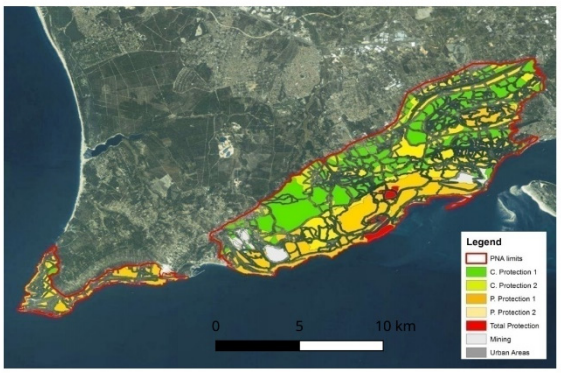

Figure 4: Informal trails accrosss the Arrábida Nature Park management zones.

3.2 Landscape Fragmentation in Arrábida Nature Park

Landscape fragmentation metrics indexes were calculated for both networks and are presented according to the PNAr management zones. It is possible to understand the rising in the number of patches present for all zones between the fragmentation when considering just the formal infrastructure and when including the potential informal trail network (Table 3). The Complementary P. Zone has the highest number of patches (751), but it was in the Partial P. Zone that showed the biggest increase in the number of patches (+427,6%). As for the Mean Patch Size, there was a decrease in all management zones between the fragmentation of the formal infrastructure and when considering also the informal trails. The Total P. Zone is the management zone that has the biggest numeric decrease in MPS (84.006,13 m2), and the Partial P. has the largest proportionally decrease (-58,65%). When comparing values of the Largest Patch Index for the formal infrastructure with results considering all networks, they increased for the Partial P. and Total P. Zones, while for the other management zones the Index decreased. The Mean Perimeter Ratio increased for all zones, with the biggest proportional (-126,7%) increasing in the Urban Zone.

4 DISCUSSION

This work presents a methodology for assessing the impacts of user-created trails and fragmentation effects in the PNAr using VGI data from a platform compiling georeferenced tracks from users.

As fitness and travel dedicated web sharing services become more common, researchers and PA managers are looking at these VGI components as an alternative to generate information on the spatial and temporal patterns of recreational use (Wong, Law and Li, 2017). One of the main reasons evoked is the capacity to generate preliminary results, that can support other types of social studies, without a high resource demand (Ghermandi and Sinclair, 2019).

The selection of Wikiloc for the assessment allowed to answer the main goals of the study, and generated significant data on the recreational use within the PNAr, more particularly on off-trail use. This agrees with other studies that obtain their datasets from online services as a VGI source (Campelo and Mendes, 2016; Norman et al., 2017). Also, the number of GPS tracks downloaded (3.635) can illustrate the popularity of the PNAr within the Lisbon Metropolitan Area for nature-based tourism and outdoor sports, with people (224 members/users) sharing their activity on this platform. Platforms like GPSies.com and Strava are also popular among outdoor recreationists and could be an alternative for this assessment. However, the former online service was acquired by AllTrails.com, a less popular platform in Europe, and the Strava dataset is not easily available to the public.

The results also show that despite most users preferring the official infrastructure, off-trail use is still happening, leading to the creation and proliferation of visitor-created informal trails. Informal use was most observed close to local cities, such as Azeitão, Palmela, and Setúbal, and also Cabo Espichel. The proliferation of informal trails around cities is many times a consequence of high levels of use around these core areas, and the lack of an appropriate formal infrastructure not matching users' recreational needs and expectations. Off-trail use can be particularly damaging in the promontory of Cabo Espichel, as this area contains plant communities that are sensitive to trampling and erosion impacts.

When compiling the amount of potential informal trails by management zone to understand the extent of impact in each zone, the fact that the complementary protection zone accommodates the greater linear extent of informal trails goes in line with the degree of protection normally allowed at this zone type. Complementary Protection Zones integrate spaces of more intensive use of the soil, where the social and economic local development must be compatible with the natural and landscape values in place. On the other side, the presence of informal trails in full protection zone suggests a potential management conflict as these are areas with high ecological sensitivity, where recreational use is

Table 3: Landscape fragmentation indices across the Arrábida Nature Park management zones.

Landscape metrics	Management zones				
	Urban	Complementary P.	Partial P.	Total P.	Overall
Number of patches					
PNAr infrastructure	479	388	29	5	901
Informal trails	474	751	153	11	1389
Mean Patch Size					
PNAr infrastructure	8.816,60	48.205,55	124.709,85	178.839,40	82.299,47
Informal trails	2.881,53	43.092,12	51.573,67	94.730,27	40.361,32
Largest Patch Index					
PNAr infrastructure	0,87	6,55	3,33	0,71	6,55
Informal trails	0,15	6,26	4,67	1,03	6,26
Mean Perimeter Ratio					
PNAr infrastructure	0,04	0,02	0,01	0,01	0,01
Informal trails	0,09	0,02	0,02	0,01	0,02

forbidden, representing a management issue for land managers.

Lastly, the landscape fragmentation assessment through the use of metrics on the management zone plan allowed to examine the impacts of informal trails development at the landscape scale. Just the impact of roads and formal trails is significant on the MPS, but when landscape fragmentation was assessed for the formal infrastructure and potential informal trails together all indices' values decrease across zones.

5 CONCLUSION

Despite the COVID-19 pandemic, the demand for the practice of outdoor recreation activities in protected areas continues to increase. Since many of these activities are concentrated on trails, potential impacts can appear in local environmental and social conditions leading to a decrease in the quality of the visitors' experience.

Nowadays, research regarding informal trails remains mainly absent, and there is a lack of a clear and objective methodology to assess the impact of user-created trails at the landscape level. To answer these concerns, this study developed a method to assess the impacts of informal trails in protected areas using VGI georeferenced tracks stored in online platforms.

The proposed procedures assessed the lineal extent of informal trails within the PNAr and the spatial distribution of user-created trails was examined through analyses of management zones and landscape fragmentation indices. These methods have the advantage to complement other monitoring studies in place (Mendes et al., 2012) allowing showcase long-term trends of visitor use, related impacts, or effectiveness of possible management and maintenance actions.

The study highlighted different areas prone to be impacted by off-track use, which represent valuable information for the managers of that area when prioritizing management decisions. These areas were emphasized using the management zonation plan, and the VGI revealed the extent of informal network impacts in each park zone. Also, the fragmentation indices calculated for PNAr produce a significant coverage of information about the different levels of impact from informal trails at the landscape scale using a minimal amount of resources.

This paper is therefore an example that bridges between a new technological methodology and the problems protected areas face, opening a discussion for these domains which can broadly interest interdisciplinary studies.

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