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Article

Exploring Visitor Patterns in Island Natural Parks: The Relationship Between Photo Locations, Trails, and Land-Use

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Abstract: Overtourism in national parks and protected areas can cause irreversible damage to the environment, compromising the quality of soil, water, wildlife, and vegetation. Thus, it is critical for park managers to have detailed information on visitor activities and spatial dynamics in order to prioritize actions capable of mitigating undesirable impacts in the most frequently visited areas. In this article, we use georeferenced trails and photographs from Wikiloc and Flickr web platforms to determine the spatial visitation patterns in the Atlantic Islands of Galicia National Park (AINP) from 2008 to 2023. Maps showing trail usage intensity and the distribution of photographs according to land use allowed us to identify the most frequented land uses by visitors and the areas of highest tourist pressure within the AINP. The results show that distribution patterns vary between platforms. Shrubland (37%) and marine cliffs (27%) were the most photographed land uses by visitors, while artificial areas (14%) were the most frequented by Wikiloc users. Cíes island emerges as the most popular tourist destination, as evidenced by the greater number of trails and photographs compared to Ons, Sálvora, and Cortegada. This study shows how social media data, specifically trails and geotagged photographs from Wikiloc and Flickr, can support and complement the monitoring of visitor use and impact in protected areas.

Keywords: wikiloc; flickr; geotagged photos; trails intensity; land use; spatial patterns; protected areas

1. Introduction

Natural parks and protected areas are essential for promoting biodiversity, ecosystem services, and human well-being [1]. In addition, they play a fundamental role in providing spaces for recreation and human connection with nature [2]. However, as tourism activities intensify, reaching ever more remote and sensitive locations, the pressure on the environment and landscape becomes more evident [3], and any changes in visitation patterns, whether spatially or temporally, have the potential to degrade the natural environment [4]. Visitor overcrowding can have significant repercussions on landscape alteration and ecosystem degradation [5], including organic contamination, damage to vegetation from trampling [6,7], soil compaction and erosion [8], loss of biodiversity [9], and excessive use of natural resources [10]. The accumulation of waste [11] or pollution from recreational boats contaminates surface and groundwater, having negative impacts on fauna and vegetation [12,13].

The extent and severity of damage are influenced by the resistance and resilience of vegetation [14], abiotic site characteristics such as soil type, topography, and hydrology [15], and additional factors including infrastructure quality, usage intensity, activity type, tourist behaviour, and

seasonality [16,17]. Many impacts are highly localised due to variations in local resource availability, sociocultural structures, and the concentration of land uses and tourist activities near prime coastal and port areas [18].

In island territories, the impact of visitors is even greater [19]. In addition to the heavy dependence on the tourism industry for economic gains [20], isolation, small spatial extent, limited resources, and fragile ecosystems are some of the main constraints that amplify the effects of tourism on islands and complicate the formulation of sustainable management and tourism development plans [21]. Therefore, it is essential to monitor and control the flows and processes resulting from tourist activities, ensuring that visitors are not excessively invasive and that the socio-cultural and environmental impacts remain bearable [22].

Understanding visitor experiences [12,23], and assessing the spatiotemporal patterns of their activities are fundamental strategies to avoid and minimise the negative impacts of tourism and ensure sustainable management of natural environments [24,25]. Visitor data can assist park managers in decision-making and policy formulation by identifying trends in tourist demand [26], generating forecasts, determining facility locations [27,28], as well as identifying negative impacts [29,30], and vulnerable areas.

In the past decade, several researchers have used georeferenced data sourced from social networks to analyse the spatiotemporal behaviour of visitors in natural environments [31,32]. This data, voluntarily shared by tourists on online platforms (e.g., Wikiloc and Flickr), can be collected remotely, in a relatively simple way, and at a low cost [5,33], proving effective in the spatial and temporal analysis of visitors [32]. Furthermore, it provides precise, real-time information on activities occurring in nature [34] and enables assessments of how people observe and value the environment [35]. Specifically, social media data has been used to determine visitation rates in parks and protected areas [36,37], usage patterns, and visitor characteristics [5,24,28,38–40], as well as visitor preferences [33,41–45]. Other authors have chosen to use these new data sources for landscape characterization [46] or to explore cultural ecosystem services [47]. Georeferenced trails and photographs not only allow the identification of the most traversed and photographed areas by visitors, but also make it possible to determine the most relevant landscape attributes [48], identify critical points with high visitation [24,45,49], and assess the impact of public use both on and off official trails [50].

However, there are few studies that analyse the spatial distribution of visitors using trails and photographs with land use in protected areas [51]. This data integration allows for the identification of the most frequented and affected land uses by tourist demand, as well as providing a more detailed insight into how visitation can impact different habitats and sensitive areas. This information can assist park managers in prioritising actions that ensure long-term conservation of affected natural resources and land uses under greater pressure and potential degradation.

To fill this knowledge gap, georeferenced data of trails and photographs shared by users of Wikiloc (<https://pt.wikiloc.com/>) and Flickr (<https://www.flickr.com/>) are used to analyse the spatial patterns of visitors according to land use in the Atlantic Islands of Galicia National Park (AINP) between the years 2008 and 2023. The analysis aims to address the following objectives:

1. Evaluate the distribution of the trails taken by visitors according to land use, and quantify the intensity of visitors along the trails;
2. Identify and analyse the most photographed areas and relate them to the park's land uses;
3. Determine the types of land use that are under the most tourist pressure using georeferenced data of trails and photographs.

Study Area

The Atlantic Islands of Galicia National Park (AINP), established in 2002 by Law 15/2002 [52], is located on the southwest coast of Galicia, Spain. It comprises the archipelagos of the Cíes, Ons, Sálvora, and Cortegada Islands, extending from the Ria de Arousa to the Ria de Vigo (Figure 1). The AINP is a protected natural heritage of extreme importance and an excellent example of the conservation status of Atlantic marine and coastal ecosystems, the associated fauna and flora species, and the cultural heritage of these areas [10]. The oceanic waters have an enormous biological variety

that is endemic and unique [6]. The park's coastlines are notable for their fine sand dunes, beaches, and rugged terrain. The cliffs cut out the ocean's horizon, while shrubby vegetation such as gorse, heather, and eucalyptus groves mark the slopes [53]. The park has a total area of 8,480 hectares, 87% of which is maritime space [54].

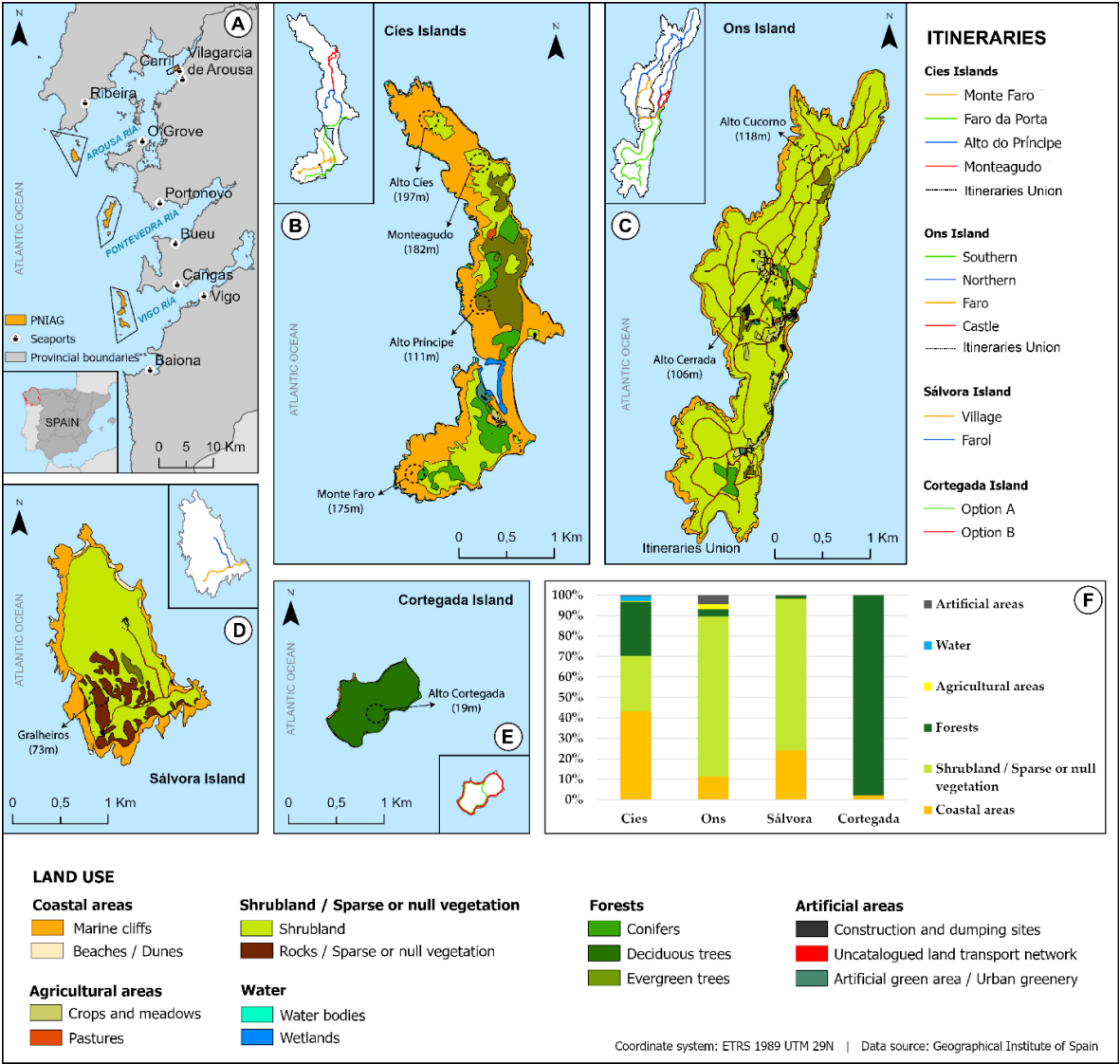


Figure 1. Location, land use, and itineraries of the Atlantic Islands of Galicia National Park: A) location of the archipelagos; B) Cíes Islands; C) Ons Island; D) Sálvora Island; E) Cortegada Island; F) Land use (%) by island.

In the Cíes Islands, the highest altitude is found in the northernmost sector, in Alto das Cíes (197 m). Similar to Ons island, the morphology presents a contrast, featuring a high cliff coast to the west and beaches to the east [55]. The steep western cliffs feature small patches of acidic, nutrient-poor [56], stony, and shallow soils [57], reflecting the oceanic influence and the scarcity of vegetation. In contrast, the lower coast dominates the eastern part, which has lower slopes and prominent sandbanks. However, these sandbanks are non-existent on the slopes most exposed to the ocean [58]. Sálvora and Cortegada are characterised by lower and more regular reliefs, with flatter contours and rounded shapes [59]. The island of Cortegada is sheltered within the Ria de Arousa, opposite the village of Carril [56], and avoids ocean waves. It has the lowest relief among the archipelagos, consisting mainly of flat areas occupied by forest cover.

Granites covered by acidic soils make up the majority of the park's geological substrate [60]. In Cíes and Ons, the rocks are mostly highly fractured granitic alkaline feldspathic rocks that formed during the Hercynian orogeny [6]. However, we can also have some metamorphic rocks [61], such as

mica schists, quartzites, and paragneisses. The flora is predominantly of the Mediterranean type, and native species dominate the archipelago's coverage, being seen both in cliff areas and on rocky slopes and vegetated cliffs [6]. The vegetation is subject to extreme weather conditions and is therefore basically shrubby [62]. Strong winds, high salinity, and shallow and sandy soils with low nutrient availability subject the plant species found on cliffs and dune systems to specific adaptations, arranging them in bands according to their tolerance to marine influence [63,64]. Due to human activity, species such as eucalyptus, acacia, and pine coexist with native species, which persist in dune and cliff environment's [65,66].

Scrubland occupies a large part of the park's land surface, particularly on the islands of Ons and Sálvora (Figure 1). On the Cíes Islands, they are especially visible on the Monteagudo and Faro Islands, interspersed with conifers. Evergreen trees, namely eucalyptus, acacias, cork oaks, and sloes (Table S1), occupy the entire Alto do Príncipe sector on the Cíes islands and are found in a scattered manner and to a lesser extent on the islands of Ons and Sálvora. Ons is currently the only populated island in the national park. On its eastern side, which is more sheltered from the winds and adverse weather conditions, there are a few houses, accompanied by their characteristic granaries, as well as the corn and potato crops linked to them [64]. Cortegada, the island with the highest tree density, closely links its vegetation establishment and dynamics patterns to the history and activities of human presence, with species such as oaks, pines, and laurels predominating [67].

According to the official statistics from the Autonomous Agency of Spanish National Parks (OAPN), except for the years 2019 and 2020, the latter marked by isolation restrictions imposed by the COVID-19 pandemic, the number of visits to AINP has progressively increased since 2017 [66]. The upward trend in the number of entries recorded between 2017 (440,661) and 2018 (489,953) was interrupted between 2019 (472,274) and 2020 (318,570). In 2021, corresponding to the post-pandemic period and the resumption of tourist activities, the national park received a total of 428,970 visitors [66]. The increase in tourism on these islands has generated new concerns related to the likelihood of their carrying capacity being exceeded, as well as the negative repercussions resulting from the overuse of resources and consequent degradation of natural ecosystems [10].

2. Materials and Methods

This research explores georeferenced data, specifically trails and photographs, shared by Wikiloc and Flickr users to analyse the spatial patterns of visitation according to land use in AINP. Figure 2 shows the methodological procedures adopted to collect, process, and analyse the georeferenced data downloaded from both platforms. Additionally, we illustrate the processes applied to the geographic data collected on the land use and geology of AINP, enabling a detailed analysis of the islands that comprise it.

Wikiloc, founded in 2006, is a content-sharing social network with over 7.6 million users that allows free downloading of trails (including photographs) and coordinate points related to outdoor activities, which are voluntarily shared by users [5]. More than 53.8 million outdoor trails and 98.3 million photographs shared on the platform demonstrate Wikiloc's popularity. Flickr, on the other hand, is a social network for sharing photos and videos available to the public since its launch in 2004. Their repository has over 60 million monthly active users, as well as more than 100 million photographers who upload and share photos of all types and places [68].

Considering the period from 2008 to 2023, tracking points (GPS points along trails) and waypoints (points with photos and annotations) have been collected from Wikiloc for the islands using a Python script. Several authors [5,69,70] have used this method to reduce processing time and manual labour required to obtain large amounts of data.

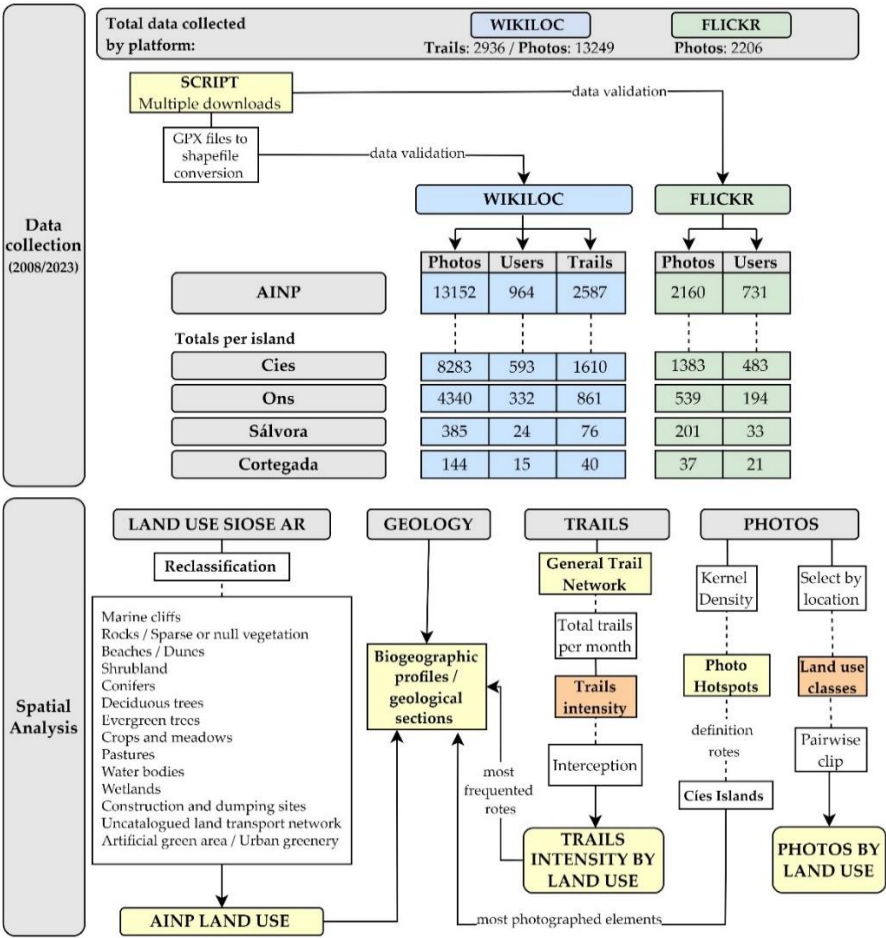


Figure 2. Methodological processes adopted in the study.

In total, 2936 trails and 13249 photographs were collected from Wikiloc by 964 users in GPX format. We chose this format because it enables the retrieval of all user-recorded points [40]. We analysed the collected list of files, eliminating those with spatial or temporal errors, then imported the validated data into ArcGIS Pro and converted it into a shapefile. From Flickr, also using a Python script, 2206 photographs were collected from 731 users. The data was exported in .xls format, containing information such as the owner's identifier, coordinates, date and time, title, text labels associated with the photographs, as well as the address link.

Each set of data extracted from Wikiloc and Flickr was combined into a single file containing all the associated metadata. Subsequently, the waypoints collected on both platforms were analysed. The presence of some repeated photographs, as well as others with non-existent dates or dates before 2008, led to the exclusion of 97 waypoints from Wikiloc and 46 from Flickr. In total, 13152 photographs from Wikiloc and 2160 from Flickr were considered valid for analysis.

In terms of the trails, it was necessary to transform the data points captured by GPS (tracking points) into a linear format to enable spatial analyses of the trails. The tracking points contain information such as latitude/longitude, altitude, date and time of the trails, location, type of activity, etc. Since one of the objectives of spatial analysis is to identify the trails undertaken within the park, 100 meters buffers were created for the islands, and selections were made based on location, assuming only the trails that were included within the buffer areas. The new outputs were carefully examined, and some GPS errors were excluded to avoid influencing the interpretation of the results.

Subsequently, using high-quality orthophotos from Spain's National Aerial Orthophotography Plan (PNOA), available at [https://centrodedescargas.cnig.es], the main paths on each of the islands were vectorized, resulting in the general trail network of AINP. Furthermore, the number of trails undertaken per month in each of the segments comprising the overall trail network of the park was counted. The sum of the data counted each month resulted in the maps depicting the intensity of

trails undertaken by Wikiloc users. After completing this process, we also mapped the itineraries of AINP to facilitate the interpretation of the results (figure 1).

The land use data (SIOSE AR_2017) for the provinces of A Coruña and Pontevedra were also collected from CNIG in GeoPackage format [<https://centrodedescargas.cnig.es>]. The land use classes (table S1) were reclassified into 14 new classes to individualise the main natural ecosystems within the park (figure 1). To assess differences in visitor influx within each of the identified ecosystems, selections were made by location, and the trail segments and photographs captured in each of the established land use classes in the previous process were individualised.

Subsequently, we used the geological map (MAGNA_50/2nd Series) at a scale of 1/50000 available on the Geological and Mining Institute of Spain's website. The original data are openly available in [IGME] at [<https://info.igme.es/cartografiadigital/geologica>].

The Terrestrial Reserve Zone (TRZ) of the Cíes Islands was further vectorized according to the cartography of conservation units from the AINP, established in the Management and Use Master Plan of the national park [71]. Wikiloc and Flickr photographs were overlaid onto the TRZ shapefile based on their respective land uses, enabling a more rigorous analysis of the impact of visitor activity on the ecosystems of the Cíes Islands that require the highest level of protection. Finally, based on results from maps detailing photograph distribution and trail intensity according to land use, we developed biogeographical profiles and geological cross-sections for the most popular tourist points.

3. Results

3.1. Global Statistics

Regarding the trails travelled by visitors to the park (figure 2), most of them were on the Cíes (62 percent) and Ons Islands (33 percent). Of all the islands that make up the national park, Sálvora and Cortegada are the least visited and have the fewest trails, accounting for only 5 percent of the total identified on Wikiloc. As with the trails, the Cíes and Ons islands were also the most photographed by visitors (Wikiloc and Flickr). The Cíes Islands accounted for 56 percent of the 13,152 photographs shared on Wikiloc, while the island of Ons accounted for 40 percent. On Flickr, only 2259 photographs were identified, a significantly lower figure compared to Wikiloc, of which 63 percent were taken on the Cíes and 26 percent on the Ons. Visitors rarely photographed Sálvora and Cortegada, which together account for no more than 4 percent of all shares on Wikiloc and 11 percent on Flickr. Considering the representativeness of the data and the popularity of the Cíes and Ons islands in terms of tourism [10,66], which boast the most intriguing natural and landscape elements in the national park, we will prioritise analysing visitor dynamics on these islands over Sálvora and Cortegada, where visitor influx has less importance.

Figure 3 shows the statistics of the photographs and trails travelled by land use in the AINP. Scrubland and sea cliffs, which make up 77 percent of the park's total area (table S2), were, not surprisingly, the most frequently photographed areas by both Wikiloc and Flickr users (figure 3-A). On Wikiloc, water bodies were the type of use with the fewest photographs identified (5), and on Flickr, pasture areas (6).

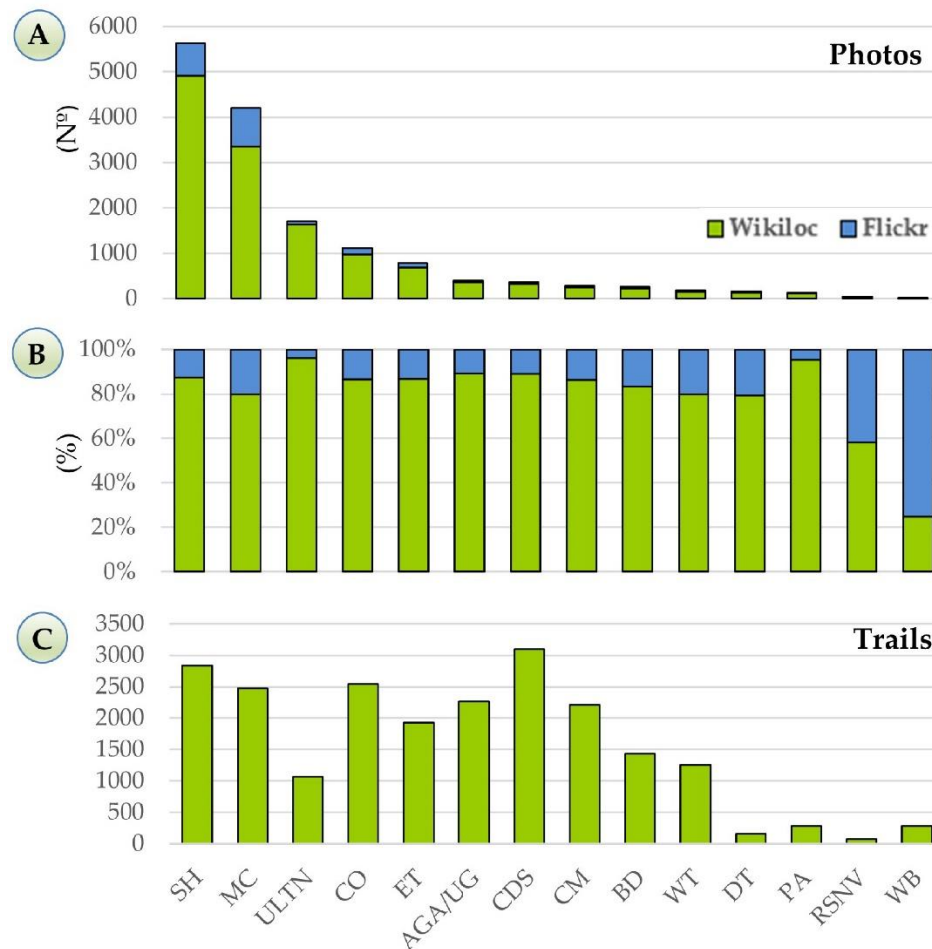


Figure 3. Global statistics of photos and trails by land use class on the AINP: (A) number of photos; (B) relative frequency of photos; (C) number of Wikiloc trails segments. Land use classes: shrubland (SH); marine cliffs (MC); uncatalogued land transport network (ULTN); conifers (CO); evergreen trees (ET); artificial green area and urban greenery (AGA/UG); construction and dumping sites (CDS); crops and meadows (CM); Beaches and Dunes (BD); wetlands and lagoons (WT); deciduous trees (DT); pastures (PA); rocks and sparse or null vegetation (RSNV); water bodies (WB).

Considering the combined data from both platforms, visitors took 5631 photographs along the scrubland and 4206 on the sea cliffs, accounting for 64 percent of the photos in the national park. Water bodies and areas occupied by rocks or sparse vegetation were the least photographed by visitors, with only 66 photographs. Wikiloc users took the majority of the photographs by land use (80 percent). Only in the least photographed areas (water bodies and areas with little or no vegetation), Flickr exceeded the number of shares made on Wikiloc (75 percent) (Figure 3-B).

In terms of trails, it was found that built-up areas, which include building areas, paved or sealed land, and dumping areas, were the land use class with the most trail segments identified on Wikiloc (14 percent) (Figure 3-C). These sites correspond to landing areas, lighthouses, and hotel services (restaurants and cafés) on the Cíes and Ons islands, located near campsites and the main beaches. On Sálvora, they are related to the cultural elements of the island (e.g., the palace and ruins of the ancient village). Scrubland (13 percent) and coniferous forests (12 percent) were the most frequented natural areas, corresponding to 11.8 kilometers of the total trail length in AINP (table S2). The sea cliffs, which are the most demanding areas in terms of access for visitors, were also very popular (11 percent). The analysis of the photographs revealed that visitors rarely frequented rocky areas with little or no vegetation and water bodies along the trails.

3.2. Spatial Analysis of Wikiloc and Flickr Photographs by Land Use

The maps in Figure 4 demonstrate that the locations chosen by visitors to take photographs coincide with the national park's touristic itineraries. However, the distribution patterns differ between the platforms. Wikiloc users concentrate their photographs along the main marked trails, while Flickr users exhibit a dispersed distribution throughout the territory. Scrubland was the land use class with the highest number of records (37 percent) among the total number of photographs taken in the AINP (15312), with the majority of these images captured on the Cíes Islands (2970) and Ons Island (2378).

The photographs are scattered throughout the scrubland in Ons, which occupies practically the entire area. In contrast, in Cíes, they are essentially restricted to the scrubland located on Monteagudo and Faro Islands. Scrubland, the land use with the most photos shared on Wikiloc (3,356) and Flickr (850), followed the sea cliffs, which occupy 36 percent of the park's total area (table S2). Of the total number of records, 91 percent are located on the Cíes islands, 6 percent on the island of Ons, and 3 percent on the island of Sálvora (table S3).

Ons island accounted for 92 percent of the 1,701 photographs taken along the national park's uncatalogued land transport network. Regarding the artificialized areas, the campsite on the Cíes Islands and the village of Curro on the island of Ons were some of the elements most photographed by visitors. Along the beaches and dune systems, 269 photographs were identified, 77 percent taken on the Cíes islands (208), with a greater incidence on Rodas beach, which is the most famous and attractive beach on the islands [65], and 16 percent on the island of Ons, most of them taken on the beaches of Canexol and Área dos Cans.

In forest areas, 2065 photographs were taken (Wikiloc and Flickr), 54 percent in areas occupied by conifers and 38 percent in areas made up of evergreen tree species. In both cases, the Cíes Islands account for more than 95 percent of the results. The Lake of Nenos, which corresponds to the only constituent polygon of the wetlands class, was one of the most photographed elements on this island, with 150 shared on Wikiloc and 38 on Flickr. Deciduous forest was the land use class with the fewest records (160) because it is almost entirely located on the island of Cortegada, which is the least visited in the national park.

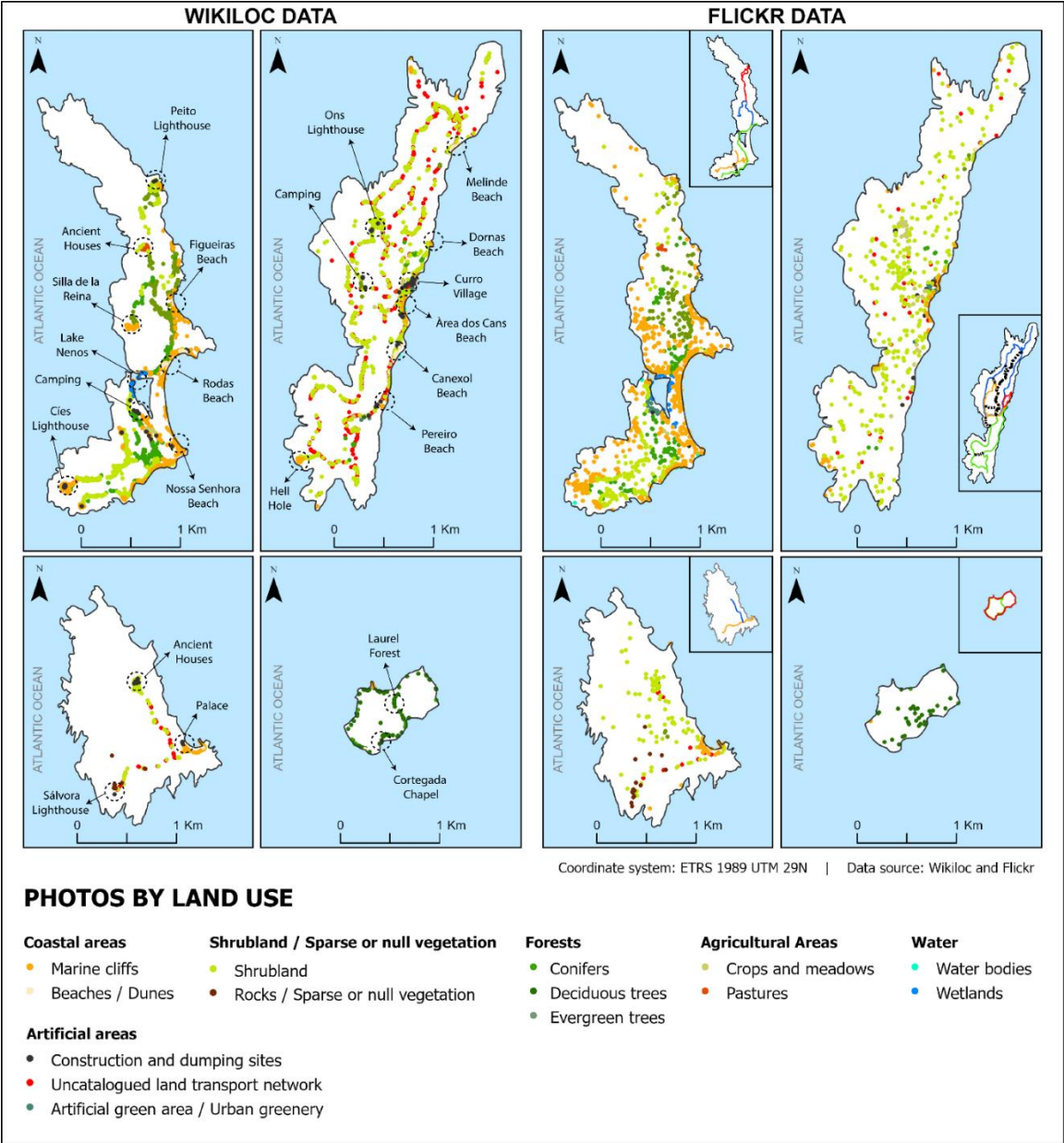


Figure 4. Photographed areas by land use in AINP.

The natural ecosystems on the Cíes and Ons islands, most frequently photographed by visitors, are located along the southern tourist itineraries. Cíes visitors take more photos of Rodas, Nossa Senhora, and Figueiras beaches, Lake Nenos, and the marine cliffs near the Cíes lighthouse (Figure 5). On Ons, the most photographed locations include Pereiro, Canexol, and Área dos Cans beaches, as well as the area with the island's most extensive and vertical cliffs, where granite walls rise about 40 meters above the ocean [72]. From this location, visitors can access the mystical cave known as the "Buraco do Inferno." On Sálvora, visitors most frequently photograph the scrublands near the ancient village, Castelo Beach, and the cliffs located to the southwest, where the lighthouse is located. Naturally, on Cortegada, the majority of photographs were taken in the deciduous forests, particularly along the existing circuit in the western part.



Figure 5. – Most photographed places on Cíes Island - (1) Marine cliffs of Monte Faro; (2) Lake Nenos; (3) Rodas Beach; (4) Figueiras Beach; (5) Nossa Senhora Beach; (6) Panoramic view to the south from Monteagudo (images source: Wikiloc).

3.3. Spatial Analysis of Wikiloc Trails by Land Use

Figure 6 illustrates the intensity of trails based on land use in the AINP. At the park level, artificialised areas accounted for 29 percent of the identified trail segments, followed by scrubland at 13 percent and coniferous forests at 12 percent, all essentially restricted to the Cíes archipelago (table S2). Visitors also frequented areas occupied by pastures, crops, and meadows, accounting for 11 percent of the park's trails, particularly in Ons. In the coastal areas, more trails were identified along the sea cliffs than along the entire length of the beaches and dune systems. This may be related to the fact that Wikiloc users are generally sportsmen who prefer only to walk the AINP itineraries.

Visitors clearly preferred the Monte Faro and Faro da Porta itineraries in the Cíes Islands (Figure 1-B), which identified more than 1,270 trails. These trails were mostly in scrubland, followed by coniferous forests and sea cliffs. These itineraries are the most attractive because they provide access to the main beaches and the most important tourist services in the archipelago. We should emphasise the intensity of the trails on Lake of Nenos, a distinctive icon of the islands and of particular ecological importance due to its diverse environments, namely sandbanks, rocks, and seagrass meadows [64].

On the Alto do Príncipe itinerary, most of the trails were in forests made up of evergreen tree species, namely eucalyptus, acacia, cork oak, and blackthorn (table S1), and on the Monteagudo itinerary, mainly in scrubland, which is the dominant type of land cover in this sector of the archipelago. In both cases, no more than 900 trails were identified. For reasons of visitor safety, environmental fragility, or the high ecological value they represent, certain areas in the western part of these itineraries do not permit access [64]. It should be noted that in these sectors, some informal trails are visible along the forest areas that have been diverted to the west. Sports visitors usually choose trails that offer shade under the cover of trees, especially on hot days [51], which may explain the visitors' preference for these areas.

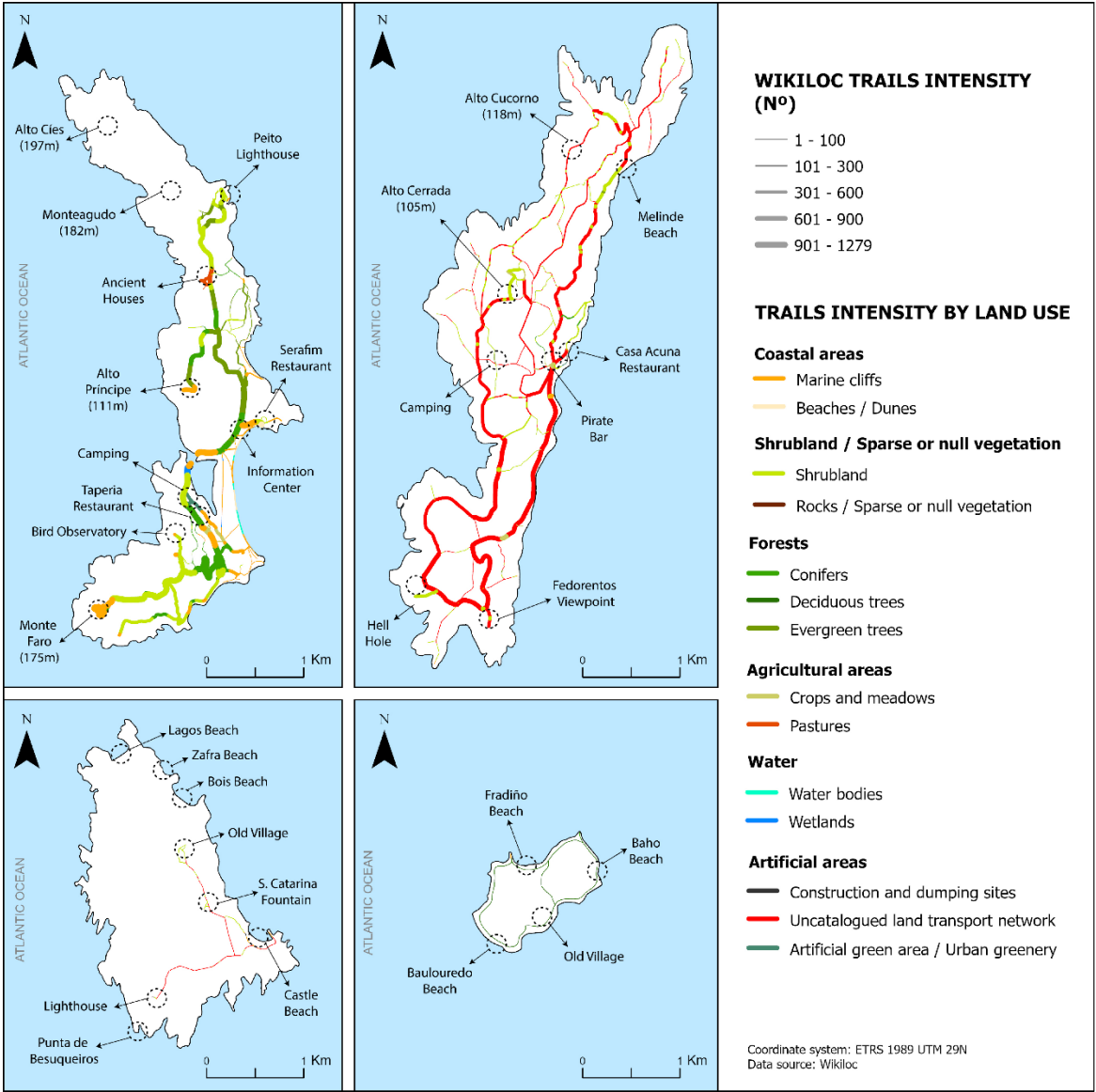


Figure 6. Trails intensity by land use in the AINP.

On the islands of Ons and Sálvora, most of the trails occur on the roads and paths that make up the AINP uncatalogued land transport network. In Ons, the southern itinerary accounted for the majority of trails, with a total of 676 trails in the most frequently visited areas. The eastern part of the northern itinerary was also very popular with Wikiloc users, with between 301 and 600 trails identified. The Faro and Castle itineraries, located in the centre of the island (Figure 1-C), were the least frequented, with no more than 300 trails along their entire length, with the exception of a small section where it's possible access to the Camping and Lighthouse Viewpoint. As in the Cíes, informal trails have also been identified on the island of Ons, scattered throughout the territory. These trails are shortcuts between routes and allow access to specific sectors of the west coast. On the island of Sálvora, no more than 87 trails per segment were identified along the existing itineraries. In Cortegada, only 45 trails were identified along the deciduous forests, which represent 90 percent of the archipelago's coverage (Figure 1-F).

4. Discussion

4.1. Justifying Factors for the Inequalities in Visitor Attendance to the Islands

Using georeferenced data from Wikiloc and Flickr, the analysis of visitation to the AINP revealed an uneven influx of visitors to the archipelagos, corroborating previous studies based on official statistics [10,66,73]. Cíes and Ons islands emerge as the most popular tourist destinations, as evidenced by the greater number of trails and photographs compared to Sálvora and Cortegada. Between 2008 and 2023, 62 percent of the trails taken in the park by Wikiloc users were on the Cíes islands and 33 percent on the island of Ons. The same trend was observed in the total number of photographs shared on both platforms, with the Cíes showing the highest number of records (56 percent on Wikiloc and 63 percent on Flickr), followed by the island of Ons (40 percent and 26 percent, respectively). Sálvora and Cortegada together accounted for only 5 percent of the park's trails, 4 percent of the total number of photographs identified on Wikiloc, and 11 percent on Flickr.

Several factors influence this overall trend in AINP visitation. For instance, there is a higher frequency and greater availability of trips to the Cíes Islands [10,74], and these islands also have a more developed tourist infrastructure compared to others [59]. These factors, combined with the diversity of landscapes of the Cíes Islands, a common factor in attractiveness [51], result in the island having the highest density of trails and photos shared on Wikiloc and Flickr. Consequently, they also increase the environmental vulnerability of cities due to the intensification of tourism. This issue is more relevant if we consider that the number of visits to the park is constantly growing, only decreasing in 2003 due to the Prestige oil tanker accident, which affected the park's waters and lasted until 2007 [73], and between 2019 and 2020 due to travel restrictions imposed by the COVID-19 pandemic [10,75].

4.2. Spatial Patterns of Use

The combined analysis of trail and photograph distribution by land use in PNIAG demonstrated that both user groups exhibit similar land cover patterns, as verified by Chai-allah et al. (2023) in rural areas of the Auvergne region in France, where trails from crowdsourcing platforms were used to assess recreational visitors' landscape preferences. Scrubland (37 percent) and sea cliffs (27 percent) were the land use classes with the most photographs identified in the AINP. In addition to the fact that scrubland occupies more than half of the park's land area (51 percent), the vegetation itself allows for open views from a slope or mountain [76], which favours taking photographs. Although scrubland occupies practically the entire length of Ons Island, 53 percent of the photographs were taken on the Cíes Islands. The cliffs, with large granite walls, especially on the Cíes, are home to some of the most important seabird colonies on the Iberian Peninsula, some of which are of global importance [10], which may explain the high number of records in these areas.

The spatial analysis of photographs according to land use revealed that the most photographed locations coincide with the park's main points of interest [5] and are located along PNIAG tourist itineraries, where trail intensity is higher [40,77]. It was also found that the distribution patterns differ between the platforms. Wikiloc users, who typically travel to the most remote locations [78], take photographs along the recommended routes, whereas Flickr users follow a limited number of trails and travel through areas that deviate from the main routes to photograph other elements scattered throughout the territory. Sports users, whose preferences and behaviours differ from those of other platform users, are the target audience for Wikiloc [46]. While Flickr primarily detects visitor flow on sightseeing tours, Wikiloc identifies trails used for hiking or climbing [79].

The higher frequency of trails in built-up areas, especially along the southern tourist itineraries on the Cíes and Ons islands, demonstrates visitors' preference for areas in the park with more developed tourist infrastructure. This aspect suggests that the presence of tourist services is a significant factor in trail selection and in meeting visitors' needs for convenience.

It is along the southern tourist itineraries on the Cíes Islands that the sites of greatest tourist pressure in the AINP are located (Figure 7). These sectors were the most photographed (map on the left) and had the highest levels of trail intensity (profiles on the right). Profile A-B covers the entire

length of the Montefaro itinerary, as well as the northern part of the Faro da Porta itinerary. Over more than 2.7 kilometres, between 901 and 1279 trails were made. Profile C-D runs along the northern edge of the Alto do Príncipe itinerary, followed by the Monteagudo itinerary to the Peito lighthouse. The terrain configuration makes this itinerary the most demanding, with between 601 and 900 trails traversed. The majority of the sites identified as most affected by tourist demand are part of the AINP Terrestrial Reserve Zone (ZTR) and require the maximum degree of protection, either temporarily or permanently. The existing roads in this unit are exclusively for conservation and park management activities, and visitor access is generally not permitted [71].

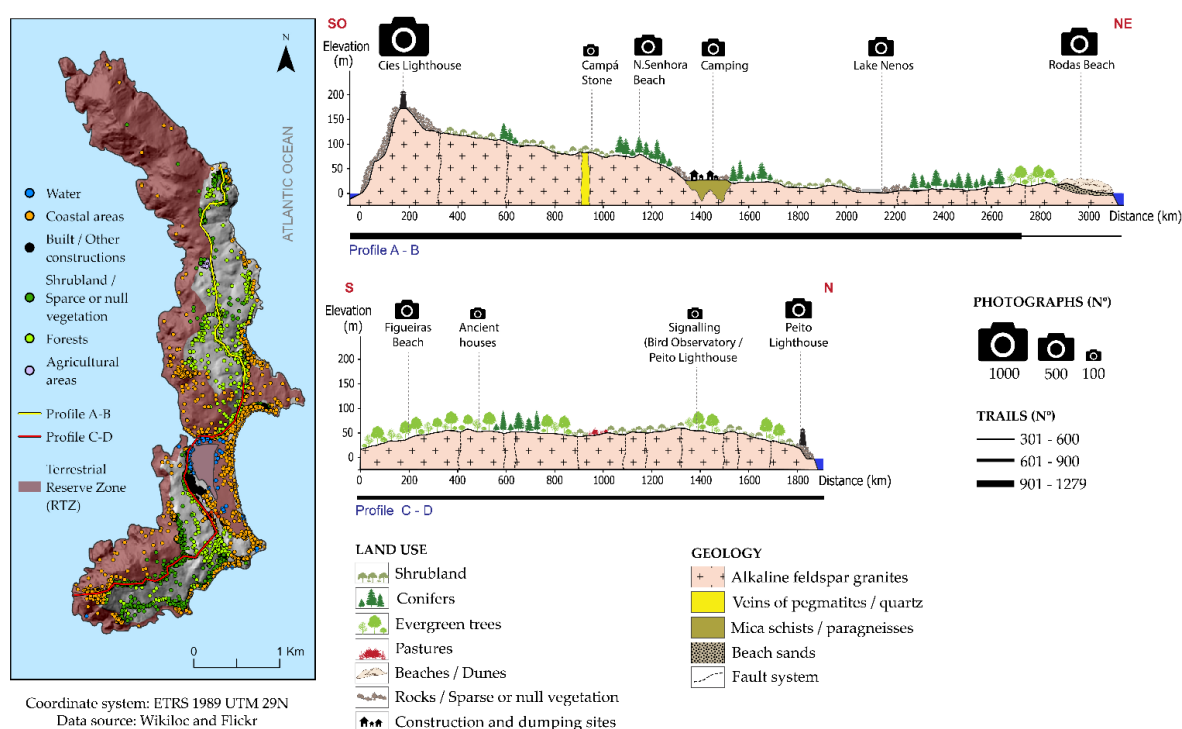


Figure 7. Graphical representation of the two main trails that Wikiloc and Flickr users perform on Cies Island, including land use, intensity of trails, and hotspot photos.

4.3. Environmental Issues

The informal trails identified allow visitors to access areas that are particularly vulnerable environmentally, especially on the Cies Islands, which reinforces the need to re-evaluate the management of the AINP official trail network. These trails, created by visitors to access inaccessible locations via official trails, such as summits and scenic viewpoints [80], are primarily unpaved, poorly designed and not managed by the park agency [81], promoting vegetation loss, changes in species composition, soil exposure and loss [82,83], hydrological cycle alteration, and landscape fragmentation [84].

Considering that the wettest habitats [81,85] and dune systems [86] are the most sensitive to trampling and are currently the most pressured by visitation in the PNIAG, specific measures should be put in place to limit the possible overload of visitors to Lake of Nenos, as well as the dune cordon of Rodas and Nossa Senhora beaches. In this type of ecosystem, the mechanical stress caused by trampling causes plants to mobilise assimilated compounds in the storage organs and increases underground biomass, which affects plant survival and reproduction, as well as germination and growth [87]. Although plant species tend to regenerate outside of the bathing season, when they come under significant pressure, habitats generally do not have the capacity to fully recover from impacts, and damage can accumulate over several years [88].

It is vital to monitor beaches regularly and over a long period of time, using aerial photographs and/or field surveys, to obtain real-time information on the state of the vegetation cover on the dunes,

as well as to identify the existence of unorganised paths in adequate time [86]. Locating trails and recreational sites in resistant and resilient areas can also be an effective method for minimising visitors' future impacts [89].

The intensive use of ecosystems and the occurrence of environmental damage can generate a reduction in the provision of benefits that ecosystems provide (ecosystem services), lead to a reduction in visitation, and eventually jeopardise the viability of local businesses that depend on them [90,91]. For tourism in protected areas to be sustainable, it must first contribute to nature conservation over the long term, not just temporarily or sporadically, and ensure that inappropriate or poorly managed public use does not jeopardise conservation [12]. Environmental awareness and public accountability are also key tools to ensure that any protection project is successful [92].

4.4. Limitations of the Research

The Wikiloc and Flickr data enabled the precise identification of visitors' spatial patterns and the land use most impacted by users demand in AINP. Thus, the use of georeferenced data offers managers an opportunity to act early and prevent damage that could otherwise occur [93]. However, there are limitations that must be considered, as they influence the rigour and representativeness of the results. Like other social media platforms, Wikiloc and Flickr do not reflect the patterns of all tourists [42,79], as they are represented by younger, wealthier, and more educated individuals [94]. Additionally, many tourists do not share their experiences on social media [43].

Other relevant constraints include the lack of detailed information about the visitors socioeconomic and demographic profile or their previous travel experiences [95], the differences in popularity among platforms [79], and the fact that the availability and use of devices for taking and sharing photos online can vary between and within countries [96]. The study's reliance on only two types of users may also have influenced the representativeness of the results. Including data from a wider range of platforms could provide a more comprehensive view of tourism's impacts on AINP.

The data quality presents additional limitations. Although there are a large number of trails available on some platforms, spatial and temporal biases in the types of data available may limit their usefulness for monitoring [39]. Due to the presence of obvious spatial errors in certain Wikiloc trails, it was necessary to exclude them in order to maintain the results' reliability. Additionally, we had to disregard a total of 97 photos, some due to users sharing them in duplicate, and others due to their non-existent or pre-study dates. The loss of data is particularly relevant in park areas, where precise delineation of high-impact sites is critical for management and conservation. The presented limitations underscore the need for a meticulous approach when using social media data to study the impacts of tourism in protected areas [5].

4.5. Future Directions

Although the study provides new insights about tourism dynamics in the AINP, further in-depth research is needed to first determine the extent to which visitors' spatial behaviour is influenced by the presence or absence of specific environmental features, and second, to assess in more detail the extent and severity of damage caused by visitor overuse in the most frequented areas.

Future research should concentrate on analysing user-shared photo content and comparing it with land use at the photo locations. This approach would allow for the evaluation and quantification of potential correlations between variables. Studies in the past have shown that content analysis of georeferenced images can help with monitoring by showing what features and aspects of the landscape are interesting to visitors [46,69,97], checking the health of ecosystems for conservation purposes [98], and maybe even finding specific issues related to visitor impact, like how wildlife and users interact [96]. Additionally, other forms of user-generated content, such as full-text hiking blogs that include narratives of visitors' experiences actively exploring the landscape, could also be explored [99].

In more remote areas without staff or where it's hard to measure, changes in photo density over time could be looked at along with regular empirical visitation surveys [33], considering the state of the soils and plants in the most used trailbeds. It would also be valuable to integrate biodiversity

indicators, such as plant and animal species richness [100] or landscape characteristics, including naturalness and openness, as these are important aspects for visitors during recreational activities [98,101]. Another research direction should focus on exploring the potential of data from photo-sharing platforms to detect different spatial behaviors based on tourists' origins, considering the information provided in user profiles and historical records (if available) as well as the type of visit conducted [95].

5. Conclusions

This study shows how social media data, specifically georeferenced trails and photographs from Wikiloc and Flickr, can support and complement the monitoring of visitor use and impact in protected areas. Access to social media data on visitor access, use, and value of various areas and infrastructures within protected areas will become increasingly important for those responsible for their management [42,43]. The results obtained provide relevant information on the influence of tourism in the PNIAG and can help park managers devise more effective measures in the areas identified as most vulnerable to some kind of environmental degradation. Cross-referencing georeferenced data with land uses showed that the most visited areas of the park are generally associated with specific types of land use. It is in the Cíes Islands, whose tourist tradition predates the designation of the national park [66], that the ecosystems most pressured by visitation are located. Particularly in Lago de Nenos and the dune systems of Rodas and Nuestra Señora beaches, management and monitoring mechanisms need to be reassessed. Park managers should promote targeted measures that consider the different land uses and their carrying capacity in order to guarantee the effective protection of the most fragile ecosystems while maintaining the tourist attractiveness of the PNIAG. Given the limited understanding of the relationship between land uses and visitor spatial behaviour [95], this study's proposed approach can serve as a model for future research examining the effects of tourism in other national parks and protected areas.

Supplementary Materials: The following supporting information can be downloaded at the website of this paper posted on Preprints.org.

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