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PROMOTING NATURE CONSERVATION IN PERI-URBAN CONTEXTS: PREFERENCES AND PERCEPTIONS OF VISITORS OF SINTRA-CASCAIS NATURAL PARK

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Abstract

Outdoor recreation in peri-urban natural parks is raising concerns about intensive trail use and conflicts among users. The Serra de Sintra (Sintra-Cascais Natural Park, Portugal) is heavily visited by hikers and mountain bikers. This study uses Volunteered Geographic Information (VGI) to map trail use patterns, identify and map the distribution of hiking and biking activities, quantify areas of user overlap (conflict risk), and assess non-compliance with park regulations.

GPS track data were downloaded from GPSies (2017) and Wikiloc (2025), processed in GIS, and overloaded on the park's official trail network. A 25×25 m grid was used to quantify use intensity, and overlap analysis identified segments used by both hikers and bikers.

Results show that hikers generally concentrate on established scenic trails, whereas mountain bikers display a broader spatial dispersion. There is a dense informal network of bike routes beyond the official plan, often crossing sensitive habitats. Overlap between groups is limited to certain corridors (e.g. core trails to Pena Palace), highlighting priority areas for conflict management. Between 2017 and 2025 the overall trail use remained high, and spatial patterns of use by hikers and bikers across the park remained similar.

These findings provide actionable spatial knowledge, and offer practical insights that can guide management decisions. Signage should be reinforced along heavily visited corridors, particularly in overlap zones where hikers and bikers converge, such as the central ridge and the main access routes to Pena Palace. Clear wayfinding and trail etiquette signs in these areas would help reduce congestion and conflicts. Additionally, targeted signage in gardens and heritage precincts can guide visitors to stay on designated paths and respect carrying capacity limits.

Keywords: Protected areas; Hiking; Mountain Biking; Spatial analysis; Volunteered Geographic Information

Resumo

A recreação ao ar livre em parques naturais periurbanos tem crescido rapidamente, oferecendo benefícios significativos para o bem-estar humano, mas também criando desafios para a conservação. Dada a sua proximidade a centros urbanos, estes parques são acessíveis a muitos visitantes, que procuram contacto com a natureza, mas também valorizam marcos culturais e infra-estruturas recreativas. Este duplo papel, como espaços ecológicos e de lazer, exige uma gestão cuidadosa para equilibrar acesso e conservação. Para tal, os gestores necessitam de dados fiáveis sobre onde, quando, e como os visitantes usam os espaços dos parques naturais periurbanos.

A Informação Geográfica Voluntária (VGI), derivada de aplicações de fitness e de atividades ao ar livre nas quais os utilizadores registam e partilham percursos GPS, é um recurso valioso para compreender de forma detalhada e económica o uso recreativo de grandes áreas. Ao contrário dos inquéritos tradicionais, dispendiosos e limitados, a VGI abrange paisagens extensas e capta informação ao nível dos percursos. Estes dados podem ser usados para mapear a intensidade da atividade recreativa, detetar trilhos informais e apoiar a gestão adaptativa de áreas protegidas.

O Parque Natural de Sintra-Cascais (PNSC) é uma das áreas naturais mais visitadas de Portugal, reconhecida pelas falésias costeiras e pela serra florestada que acolhe numerosos marcos culturais, como castelos, palácios e conventos. O pedestrianismo é uma das atividades mais populares no PNSC, e a prática de Bicicleta Todo o Terreno (BTT) tem crescido rapidamente. A proximidade a Lisboa e o fácil acesso implicam forte pressão recreativa, especialmente aos fins de semana e feriados, levantando preocupações quanto à erosão de trilhos, perturbação de habitats e conflitos entre utilizadores.

O objetivo desta dissertação foi caracterizar os padrões espaciais de pedestrianismo e BTT no PNSC, e ao longo do tempo, identificar zonas de potencial sobreposição destes usos. Foram compilados dois conjuntos de dados de VGI, um da plataforma GPSies (2017) e outro da Wikiloc (2024/2025). Apenas foram usadas pistas GPS públicas classificadas como pedestrianismo ou BTT que interceptavam a área de estudo. O conjunto de dados inclui 1,734 percursos de BTT e 276 de pedestrianismo da GPSies, e cerca de 1.400 percursos de cada atividade da Wikiloc. Todas as pistas foram importadas para um SIG, e utilizando uma grelha uniforme de 25 × 25 m sobreposta ao parque, e para cada célula foi determinado o número de percursos que a atravessavam. Com base nesta informação, foram gerados mapas de intensidade de pedestrianismo e BTT, considerando 10 classes de utilização, em que 0 indica ausência de uso e 10 corresponde à atividade máxima. As células usadas por ambas as atividades foram identificadas como potenciais pontos críticos de interação.

Em 2017, o pedestrianismo era limitado em cobertura espacial, com grande parte do parque sem registo de atividade. Os percursos concentravam-se na serra central, ligando a vila de Sintra ao Palácio da Pena e ao Castelo dos Mouros. O conjunto GPSies documentou apenas algumas centenas de percursos, e as atrações culturais não eram ainda focos principais. Em 2025, o pedestrianismo expandiu-se significativamente. O número de percursos aumentou e a proporção do parque com registo de atividade cresceu. Os percursos espalharam-se pelas secções ocidentais e costeiras, em torno do Cabo da Roca e da Praia Grande, embora as maiores concentrações continuem nas zonas altas e próximas de marcos culturais. O aumento da atividade pedestre em torno de palácios e castelos está provavelmente relacionado com esforços recentes de restauro e promoção turística.

O BTT seguiu uma trajetória diferente. Em 2017, o BTT já estava bem representado, com mais de 1.700 percursos registados, cobrindo uma parte ampla das redes florestais e encostas. Os ciclistas usavam frequentemente trilhos não oficiais, expandindo a rede efetiva além do mapa oficial. Em 2025, o BTT

manteve-se generalizado, mas a cobertura espacial contraiu-se ligeiramente. As zonas de maior utilização persistiram ao longo das serras e perto do Convento dos Capuchos, mas a zona com uso intermédio diminuiu, indicando consolidação em circuitos preferenciais em vez de expansão.

Em geral, observou-se uma baixa sobreposição espacial entre o pedestrianismo e o BTT. Poucas células mostraram utilização intensa simultaneamente por pedestres e ciclistas e, em 2025, apenas algumas centenas de células registaram intensidade moderada ou elevada para ambas as atividades. A sobreposição ainda que baixa a moderada ocorreu em torno da vila de Sintra, nas rotas para o Convento dos Capuchos e nos corredores costeiros junto ao Cabo da Roca. Isto sugere que, embora partilhem alguns espaços, os principais pontos de atração das atividades são distintos.

O pedestrianismo no PNSC intensificou-se e diversificou-se entre 2017 e 2025, tanto no número de percursos como na dispersão espacial. Mais visitantes exploram agora não apenas os trilhos icónicos da serra, mas também as paisagens costeiras e interiores. Isto reflete tendências mais amplas em contextos periurbanos, onde cresce a procura por natureza acessível e experiências culturais. Ainda assim, o BTT permanece popular, mas espacialmente estável, com pouca expansão. A persistência em trilhos florestais e serras, especialmente junto aos Capuchos, demonstra a preferência dos ciclistas por terrenos desafiantes e circuitos existentes. A dependência de trilhos informais, contudo, revela riscos potenciais, como erosão, perturbação de habitats e o desafio de gerir rotas fora da rede oficial.

A sobreposição entre o pedestrianismo e o BTT é limitada, mas onde ocorre tem implicações claras. A utilização partilhada de trilhos serranos e costeiros cria oportunidades de conflito, devido a diferenças de velocidade e comportamento. Mesmo sobreposições moderadas, quando combinadas com encostas íngremes ou trilhos estreitos, podem representar riscos de segurança e degradação ecológica.

A concentração das atividades de caminhada e BTT em torno de pontos culturais e cénicos sublinha a importância da gestão da visitação no PNSC. Os fluxos de visitantes podem ser direcionados através de sinalética, áreas de descanso e limites ao tamanho dos grupos. O reforço dos trilhos e o controle da erosão podem ser necessários nos percursos mais utilizados. A presença de rotas de BTT não oficiais levanta questões de formalização. Importa compreender, se alguns circuitos informais muito usados podem ser designados como trilhos oficiais, garantindo manutenção e reduzindo o impacto ecológico, enquanto áreas sensíveis podem necessitar de encerramento ou recuperação.

Em termos de mitigação de conflitos, o zoneamento pode designar trilhos exclusivos para pedestres ou ciclistas, especialmente em áreas de uso partilhado recorrente. O desenho de percursos diferenciados, permitindo orientar os visitantes para trilhos onde predomina uma das atividades, pode minimizar conflitos e melhorar a experiência. Em trilhos mistos, medidas como controle de velocidade, circulação em sentido único ou separação temporal podem melhorar a segurança.

Embora ofereça resolução e cobertura sem precedentes, a VGI é tendenciosa para utilizadores tecnologicamente ativos que registam e partilham percursos. Visitantes ocasionais podem estar sub-representados, e mudanças na popularidade das plataformas podem afetar a cobertura. Ainda assim, o grande número de percursos e a consistência dos padrões espaciais registados no PNSC sugerem que a VGI é uma ferramenta útil para identificar áreas de maior atividade. Para além da intensidade espacial, este estudo oferece um quadro metodológico que integra dados GPS gerados pelos utilizadores com cartografia de intensidade baseada em SIG. A abordagem demonstra o valor do crowdsourcing para compreender a recreação em áreas protegidas periurbanas, oferecendo uma ferramenta replicável e rentável para os gestores.

Globalmente, esta dissertação aponta para a necessidade de uma gestão proativa e informada espacialmente, capaz de equilibrar a elevada procura recreativa do PNSC com a conservação ecológica e

cultural. Ao alinhar infraestruturas, zoneamento e educação dos visitantes com os padrões de uso observados, o PNSC pode continuar a oferecer oportunidades recreativas de qualidade, salvaguardando simultaneamente as suas paisagens e património. A persistência de áreas de forte utilização junto a marcos culturais e cénicos evidencia a atração duradoura dos locais icónicos, enquanto a expansão do pedestrianismo indica uma procura crescente e diversificação das motivações dos visitantes. Estes conhecimentos devem orientar a gestão adaptativa, assegurando que medidas como a melhoria, o redirecionamento e o zoneamento dos trilhos são fundamentadas em evidência empírica. Num contexto em que os parques periurbanos enfrentam pressões crescentes, esta dissertação demonstra os desafios e oportunidades de utilizar a VGI para uma gestão sustentável da recreação, oferecendo um modelo replicável para paisagens semelhantes em todo o mundo.

Palavras-chave: Áreas protegidas; Pedestrianismo; BTT; Análise espacial; Informação Geográfica Voluntária

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List of Abbreviations and Codes

BTT: Bicicleta Todo-o-Terreno (mountain biking, PT term)

CMAJ: Canadian Medical Association Journal

FAO: Food and Agriculture Organization

FCUL: Faculdade de Ciências da Universidade de Lisboa

GIS: Geographic Information System

GPX: GPS Exchange Format (file format)

HIK: Hiking

ICNF: Instituto da Conservação da Natureza e das Florestas

ICOMOS: International Council on Monuments and Sites

IP: Instituto Público (public institute)

IUCN: International Union for Conservation of Nature

MTB: Mountain Biking

PNSC: Parque Natural de Sintra-Cascais

UNESCO: United Nations Educational, Scientific and Cultural Organization

VGI: Volunteered Geographic Information

1. Introduction

1.1. Tourism and recreation in protected areas

It may seem that all nature holds value. However, some territories have long been altered by human activity: forests have been cut down and replanted, factories or city parks have been built. And yet, there are places where untouched nature still remains, and ecosystems that cannot be recreated by human effort. All over the world, there are territories where economic activity is restricted or prohibited for the sake of nature conservation. These protected areas encompass national parks, nature reserves, wilderness areas, and other areas focused on conservation. For instance, since 1990 an estimated 420 million hectares of forest have been lost worldwide through conversion to other land uses, and only about 23% of the Earth's land surface is now classified as wilderness relatively free from direct human impact (FAO, 2020; World Economic Forum, 2018). This underscores the critical importance of protected areas in preserving remaining natural ecosystems.

Conserving wild nature matters not only out of respect or affection for the environment. It is essential for the quality of human life. Protected areas help maintain the stability of environmental conditions that are crucial for human well being. They contribute to climate regulation, and to maintain natural processes and play a vital role in conserving and restoring populations of rare and endangered species, thus helping to prevent the species losses that can disrupt food chains and ecosystem functions, ultimately threatening human life (Chivian, 2001). Finally, nature reserves, national parks, and natural parks offer invaluable opportunities for scientific research, environmental education, and ecotourism (Pickering et al., 2018).

Over the past twenty years, the way people experience tourism and outdoor recreation has changed quite a lot. Today's tourists are more independent and well-informed, and many express deep environmental concerns. They seek meaningful and personal experiences, and to connect with nature and culture while remaining active. For instance, in the UK 85% of holiday travelers felt it was important not to damage the environment, 77% wanted their trip to include experiencing local culture and food, and 71% believed tourism should benefit local people (Dimitrijoski, 2000). Experienced ecotourists rank wilderness settings, opportunities for wildlife viewing, and activities such as hiking and trekking among the most important elements of trips. In fact, the top motivations of ecotourists are "enjoying scenery/nature" and seeking "new experiences/places," (Dimitrijoski, 2000).

Engaging in nature-based tourism and outdoor recreation can positively impact both physical and mental health. Studies in public health and environmental psychology have found that spending time in natural settings or green spaces can lower stress levels, improve mood, and even enhance immune function. In particular, outdoor activities such as hiking, walking in parks, or "forest bathing" (immersive walks in the forest) are associated with reduced stress hormones and improved psychological well-being (Li 2022; Wolch et al., 2014). These benefits make ecotourism and outdoor recreation not just enjoyable, but also a valuable contributor to a healthy lifestyle.

Tourism centered on nature and the outdoors has grown significantly faster than conventional tourism. While global tourism grew around 4% annually in the 1990s, nature-based travel increased by an estimated 10–30% per year (Samal et al, 2023). By the late 1990s, ecotourism and other nature-related travels accounted for roughly 20% of international tourist trips (Dimitrijoski, 2000). The world's

protected natural areas are estimated to receive around 8 billion visits every year, which vividly illustrates the growing popularity of outdoor recreation in these settings (Balmford et al., 2015).

The increased demand for outdoor recreation has undoubtedly created greater pressure on protected areas, posing numerous challenges. Popular parks around the world are struggling with issues such as environmental degradation, pollution, trail erosion, disturbance to wildlife, crowding, and even conflicts between different groups of users (Eagles et al., 2002). However, if well managed, tourism and recreation in protected areas can support local economies, engage the public in conservation, and generate funds and awareness for protecting these landscapes. In this sense, tourism can be a valuable tool for conservation by fostering appreciation for nature and providing financial resources for management (Pickering et al., 2018). Effective planning, setting limits on use, providing adequate infrastructure, and educating visitors, are essential to balance enjoyment of nature with the need to preserve it (Eagles et al., 2002).

In practice, recreational use in protected areas does not occur only on official, signposted trails. In Portugal, including in Sintra-Cascais Natural Park, visitors also use paved and unpaved roads, forest tracks and other existing paths throughout the landscape. This wider use is not necessarily illegal, as many of these routes follow long-established access roads or public rights of way. However, illegal or clearly unauthorised use also exists, and land owners as well as park managers have raised concerns about off-trail riding, new informal tracks and access to sensitive areas.

1.2. Visitor conflicts and monitoring approaches in protected areas

Beyond ecological consequences of tourism, social conflicts between different visitors are a growing concern in the management of protected areas. On multi-use trails, disagreements frequently arise between hikers and mountain bikers, who differ in their expectations, speed, and patterns of trail use (Santos et al., 2016; Tumes, 2007). Noise, fast movement, or spatial dominance can lead to perceived or actual safety issues, reducing enjoyment and causing frustration. Specific conflict hotspots between runners and cyclists highlight the need for spatially-informed solutions such as trail segregation, improved signage, or temporal zoning (Santos et al., 2016). Conflicts may further extend to other activities, such as rock climbing, dog walking (especially off-leash), horseback riding, and the use of Segways or electric scooters, adding new layers of complexity. Besides, different stakeholders, including local communities, conservation authorities, and user groups, often hold conflicting values and perspectives on appropriate trail use (Rossi et al., 2013).

Addressing these tensions requires a holistic and participatory approach to management of protected areas (Moore, 2004). This includes engaging different user groups in dialogue, providing education about trail etiquette, and developing evidence-based policies that consider everyone's needs (Moore, 2004; Wolf et al., 2018). In this broader context, spatial data plays a pivotal role in decision-making. In particular, technologies such as GPS tracking, remote sensing, and GIS analysis enable managers to map visitor flow, identify congested areas, and assess how use patterns change over time (Korpilo et al., 2017; Wolf et al., 2018). Traditional methods for understanding visitor behavior, including surveys, interviews, direct observation by rangers, and mechanical counters or GPS trackers provide detailed information on visitor demographics, motivations, satisfaction, and compliance with rules (Veal, 2011). For instance, a combination of boat landing counts, automatic trail counts, time-lapse cameras, and visitor surveys to assess peak visitation periods and areas, and perceptions of crowding, helped manage carrying capacity and improve the visitor experience by adjusting infrastructure and

timing (Mendes et al., 2020). Similarly, GPS tracking has been employed to understand spatial behavior in parks, and where different people roam from trailheads or campgrounds (Shoval & Isaacson, 2007). However, such traditional methods can be time-consuming, labor-intensive, and often limited in scope. Surveys might miss certain groups of visitors or be subject to self-report biases, and mechanical counters can sometimes miscount or be thrown off by environmental factors (Rossi et al., 2015). These limitations have paved the way for newer approaches that take advantage of digital data sources.

In recent years, the integration of spatial technologies, particularly Volunteered Geographic Information (VGI), has significantly enhanced the capabilities for monitoring and managing recreation. VGI offers a powerful, low-cost complement to conventional monitoring by leveraging data that visitors are already willingly generating, and can reveal not only use intensity but also preferences for terrain, elevation, trail type, and distance, as well as areas of high spatial overlap between user groups (Wolf et al., 2012; Santos et al., 2016). Importantly, VGI allows researchers to observe how people behave without interrupting them with surveys, and provide large amounts of up-to-date data directly from real users. As outdoor enthusiasts increasingly track and document their hikes, runs, or rides using smartphone apps, and they often share this data publicly (either deliberately or by default), the resulting pool of crowd-sourced GPS tracks becomes a gold source of data for park managers (Campelo & Mendes, 2016).

The strengths of VGI lie in its scale, timeliness, and spatial precision. Unlike field surveys that are typically conducted only during certain seasons or on select days, data from mobile apps provide continuous input over large time spans and across wide areas. This makes it possible to monitor seasonal trends e.g. shifts in use from summer to winter), catch emerging hot spots, and observe visitor responses to changes in facilities or regulations. The spatial detail is often much higher than that traditional methods can capture, with uploaded tracks logging the exact paths visitors took, and allowing the analysis of route choices, distances traveled, speeds, and stop locations (Korpilo et al., 2017). This level of granularity can reveal patterns that in-person observation might miss. It can show, for instance, that visitors often detour off official trails to reach a viewpoint, or how far they typically travel from a parking lot before turning back. Aggregating thousands of such tracks can describe which trails are most heavily used and identify unofficial “social trails” created by visitors, all without a single ranger having to observe them directly (Campelo & Mendes, 2016; Santos et al., 2022).

Promising sources for monitoring and managing recreation using VGI also come from geotagged social media posts and photographs (Heikinheimo et al., 2017). Visitors often post about their experiences on platforms like Instagram or Twitter, and these posts frequently include location data and are accompanied by photos of scenic spots. When analyzed together, geotagged photos act as crowd-sourced observations of visitation, from which researchers can infer the most popular attraction sites and even gauge visitor sentiments or activities at those places (Heikinheimo et al., 2017). Social media data tend to closely correspond with traditional visitor counts, but also to reveal new types of activities and visitation patterns (e.g. times of day or week with unexpected spikes) that formal surveys do not capture (Heikinheimo et al., 2017).

Although webshare and fitness platforms have their own user bases and technical characteristics, studies in protected areas in Portugal and abroad suggest that the preferences and spatial behaviour of hikers and mountain bikers are broadly similar across these services. Findings from Australia and North America, for example, show consistent patterns in how these groups select trails and move through the landscape even when data are drawn from different VGI sources (Pickering & Norman, 2017; (Walden‑Schreiner, Leung, & Tateosian, 2017).

Despite its many advantages, VGI has, however, notable limitations and must be used thoughtfully (Venter et al., 2023). One primary concern is that not all visitors use tracking apps or social media at the same rate. People who contribute data are usually comfortable with technology or motivated to track their activities, and often include younger visitors or avid recreationists whereas older people, casual visitors, or those without easy access to technology may be little represented (Venter et al., 2023). Additionally, VGI datasets might overemphasize certain activities (e.g. mountain bikers who track every ride) while undercounting others (e.g. picnickers or wildlife watchers who don't use apps). Privacy and data access can also be issues, because not all data are publicly available, and there are ethical considerations in using people's location data.

The best outcomes in monitoring and managing recreation often come from integrating multiple information sources, including traditional methods. On-site surveys and interviews can reveal the "why" - the motivations and satisfaction levels behind visitor uses - while VGI and spatial analysis show the "where" and "when" of those uses. When assembled, these methods allow managers to cross-verify findings and fill gaps in each other's coverage, greatly improving the accuracy and depth of visitor use monitoring, and can directly inform management actions. For instance, if surveys show that visitors highly value solitude and a sense of wilderness, VGI maps can be used to identify which areas of the park remain relatively quiet and which are heavily frequented, and actions to protect the tranquil areas, by limiting development or access there, or to disperse use away from overcrowded spots by promoting alternative trails or opening new routes in underused zones, can be taken. Similarly, if GPS track data reveals that a previously low-use trail has seen a sudden surge in popularity, the maintenance on that trail may be increased, by adding signage about etiquette or safety, or deploying a ranger on busy days to prevent issues. By anticipating problems in this way, managers can avoid trail degradation and nip user conflicts in the bud. Overall, embracing these modern monitoring techniques leads to more adaptive management, with on-the-ground actions being adjusted in near real-time based on evidence, which is crucial for protecting park resources while also enhancing visitor experiences.

1.3. Management of tourism in peri-urban protected areas

Achieving a sustainable balance between tourism use and nature conservation is especially critical in peri-urban protected areas located near major population centers. These natural areas, located on the edges of cities, retain more natural conditions, with less urban noise, or pollution. are easily accessible for large numbers of people seeking recreation. Naturally, in addition to local residents that visit them frequently, peri-urban protected areas also attract tourists from farther away, resulting in high visitation pressure (Rossi et al., 2015). Consequently, peri-urban natural areas often experience intense human-environment interactions (Douglas, 2006; Lopes & Silva, 2022). Understanding these interactions requires a multifaceted perspective, drawing on several theoretical frameworks that shed light on how visitors use and impact these settings, and how their experiences are shaped by environmental and social factors. Key frameworks include the social-ecological systems approach, recreation ecology, concepts of landscape perception, and considerations of proximity and accessibility (Miller et al., 2022; Morse, 2020).

Peri-urban parks are expected to serve multiple functions, including the conservation of biodiversity, provision of recreation and leisure opportunities for the public, and in some cases, also support of local livelihoods and preservation of cultural values (Wei & Tesemma, 2018). The social-ecological system approach encourages an adaptive management mindset, where actions are adjusted based on monitoring outcomes and stakeholder feedback. It also highlights the importance of

community involvement and education, since the support of local users is often critical for the success of conservation measures (Plummer & Fennell, 2009).

The need to accommodate multiple stakeholders (e.g. visitors, local communities, conservationists, tour operators), with conflicting interests, also adds complexity to the management of peri-urban parks. Even in less-visited or more remote protected areas, lack of resources and overlapping responsibilities among multiple government bodies undermine coordinated decision-making and day-to-day supervision (Siltanen et al., 2022). This suggests that peri-urban parks, which often have higher visitation and more stakeholders, may face even greater coordination challenges. Peri-urban protected areas typically support a wide range of outdoor activities for visitors, from hiking and mountain biking to dog walking, horseback riding, running, and bird watching, reflecting the high demand for recreation near urban centers (Rossi, Pickering, & Byrne, 2012). Adopting a social-ecological system perspective is useful in this context, as it reminds managers that these parks are not isolated islands of nature, but part of a coupled system of people and environment. However, managing such diverse and intensive uses is complicated as limited staff and financial resources can constrain maintenance and enforcement, and the jurisdiction over these areas may be fragmented among different agencies or municipalities.

Another important management focus is gaining insight into how, where, and why people use peri-urban protected areas. Understanding visitor spatial uses and preferences has become fundamental for effective planning especially as these parks face risks like habitat fragmentation, vegetation loss, and frequent user conflicts (Lopes & Silva, 2022). A growing body of research emphasizes the importance of spatial factors - particularly distance and accessibility - in shaping people's use of urban green spaces (Shu et al., 2024). Although little is still known about visitation patterns specific to peri-urban protected areas, available evidence suggests that demographic and geographic factors significantly influence recreation behavior (Arnberger & Eder, 2011; Rossi et al., 2015). For instance, older people tend to visit parks nearby, whereas younger people tend to travel longer distances, irrespective of the activities they were engaged in (Rossi et al., 2015). This runs contrary to earlier research indicating that people travel farther only for specific or committed recreational activities, such as club sports or specialized leisure (McCormack et al., 2006), and highlights the importance of understanding where different visitor groups come from and what they expect from their visit.

Research in recreation ecology further underlines that use patterns are critical in shaping recreation impacts in the environment and the way they can be managed (Liddle, 1997; Monz et al., 2010). The severity of such impact depends on the type and intensity of use, as well as the ecosystem's resistance and resilience (Monz et al., 2010; Pickering & Hill, 2007). Even low-impact activities, when too frequent, or moderate levels of hiking and biking on unpaved trails, can lead to vegetation damage, soil compaction, wildlife disturbance, and other ecological changes along trails and in campsites (Pickering et al., 2011). Faster and mechanized activities (e.g mountain biking) tend to cause impacts more quickly or intensely than slower activities, even if the overall use level is low, because they tear up soil or vegetation with greater force (Pickering et al., 2011). On the other hand, some environments are more tolerant than others. For example durable surfaces, such as rocky ground, or areas with fast-growing vegetation can withstand heavier use and recover more quickly from trampling, whereas fragile habitats, like wet alpine meadows or dune systems, may be harmed even by a single visitor passing through (Hill & Pickering, 2009). Recreation ecology recognizes these differences, and provides guidance on setting limits of acceptable change or carrying capacities for trails, designing and hardening trails to

reduce erosion, and restricting access to particularly sensitive areas before irreversible damage occurs (Monz et al., 2010).

One issue many peri-urban parks face is the proliferation of informal trails created by visitors seeking shortcuts or novel routes, which can fragment habitats, increase erosion, and disturb wildlife off the established paths (Wimpey & Marion, 2011). Even moderate recreation pressure, if not managed, may lead to noticeable declines in vegetation cover and biodiversity along unofficial trails, compounding the impact on the ecosystem (Ballantyne & Pickering, 2015). These problems become worse when park agencies lack sufficient resources to maintain trails or monitor conditions, or when there are no clearly defined zones for different types of use (e.g. dedicating certain trails only to hikers or only to bikers). This highlights the necessity for managers to account for differences in visitor origin and frequency when planning facilities and recreational opportunities. For instance, local residents might benefit from multiple small trailheads scattered around a park to reduce congestion at any single entry, whereas out-of-town visitors might be funneled toward a main entrance with visitor information centers and parking.

Park´s accessibility is not only about distance, but also includes the availability of public transport, parking capacity, clear signage and maps, and information about attractions, and raises important management issues. Good connection to public transit, can reduce car traffic and associated impacts, but it might also increase total visitation on weekends. Managers must understand where visitors are coming from and how often they visit, to design strategies to distribute visitation pressure. This may include directing visitors to lesser-used areas or alternative trails, improving facilities (e.g. picnic areas, viewpoints) in quieter zones to make them more appealing, and providing good public transportation options or shuttle services to spread out the flow of people. By diversifying the opportunities and access points within a park, managers can alleviate stress on the most sensitive or overused habitats while still allowing people to enjoy nature.

Ultimately, managing a peri-urban protected area requires a delicate balance between providing access to nature for urban populations and visitors, while safeguarding the ecological and cultural values of the area.

1.4. Objectives

This dissertation aims to provide a spatially informed foundation for sustainable recreation management in the Serra de Sintra, a high-use zone within the Sintra-Cascais Natural Park (PNSC). Located less than 30 kilometers from Lisbon, the PNSC, offers a valuable case for examining the use dynamics of peri-urban protected areas in practice. Effective recreation management for such an area requires not only ecological monitoring but also a thorough understanding of visitor behavior, including where people go, how they behave, which types of use are prevalent across the landscape, and where issues such as overcrowding or user conflicts are likely to occur. By using VGI data collected in 2017 and 2025, through GPSies and Wikiloc, this dissertation will contribute to inform management strategies that minimize environmental damage, mitigate user conflicts, and enhance the quality of visitor experiences in Serra de Sintra.

The specific objectives of this dissertation are to:

- Analyze the spatial patterns and intensity of key recreational activities (i.e. hiking and mountain biking) in Serra de Sintra.
- Identify visitor preferences regarding trail characteristics and compliance with designated park trails.

- Assess areas of spatial overlap and potential conflict between different user groups.
- Analyse variation in recreational use patterns and identified conflict areas in relation to 2017.
- Provide a spatially informed foundation for decision-making that supports improved recreational planning in the Sintra-Cascais Natural Park.

2. Material and methods

2.1 Study area

The Sintra-Cascais Natural Park is a protected area in western Portugal, covering an area of about 14,583 hectares (Figure 2.1). Previous studies have shown that natural, cultural and aesthetic assets are key factors attracting visitors to the Sintra-Cascais Park (Lopes & Silva, 2022). The combination of lush forests, mountain vistas, and cultural heritage sites is a major part of its allure (Lopes & Silva, 2022). Visitors come here for many activities, including sightseeing, birdwatching, mountain biking, hiking. The last one, in particular, is especially popular because of the park's well-maintained trails and forest paths, which allow visitors to experience both natural and cultural sites (Fowler & Collin, 2000) (Figures 2.2 and 2.3).

The park's proximity has made it a popular green leisure destination for Lisbon's residents, and its easy reach attracts a large number of visitors from different social groups, each with diverse interests and needs (Europarc Federation, 2021). Indeed, Sintra-Cascais Natural Park being less than an hour from a major city (Lisbon) has a very high visitation on weekends and holidays, leading to crowding at popular sites and greater wear-and-tear on trails (Lopes & Silva, 2022). The park is also well connected to Lisbon, making it popular among urban residents, and because it is easy to reach, it also attracts diverse users with different expectations (Fowler & Collin, 2000). Yet this ease of access brings challenges, as heavy daily use can gradually degrade the very natural features people come to enjoy.

The park maintains a network of officially designated trails for both hiking and mountain biking. The trail system varies considerably in length, difficulty, and terrain and is designed to accommodate a wide range of visitor profiles. Options include short, accessible walks through the historic centre, as well as more demanding routes across the Serra de Sintra (Tables 2.1 and 2.2).

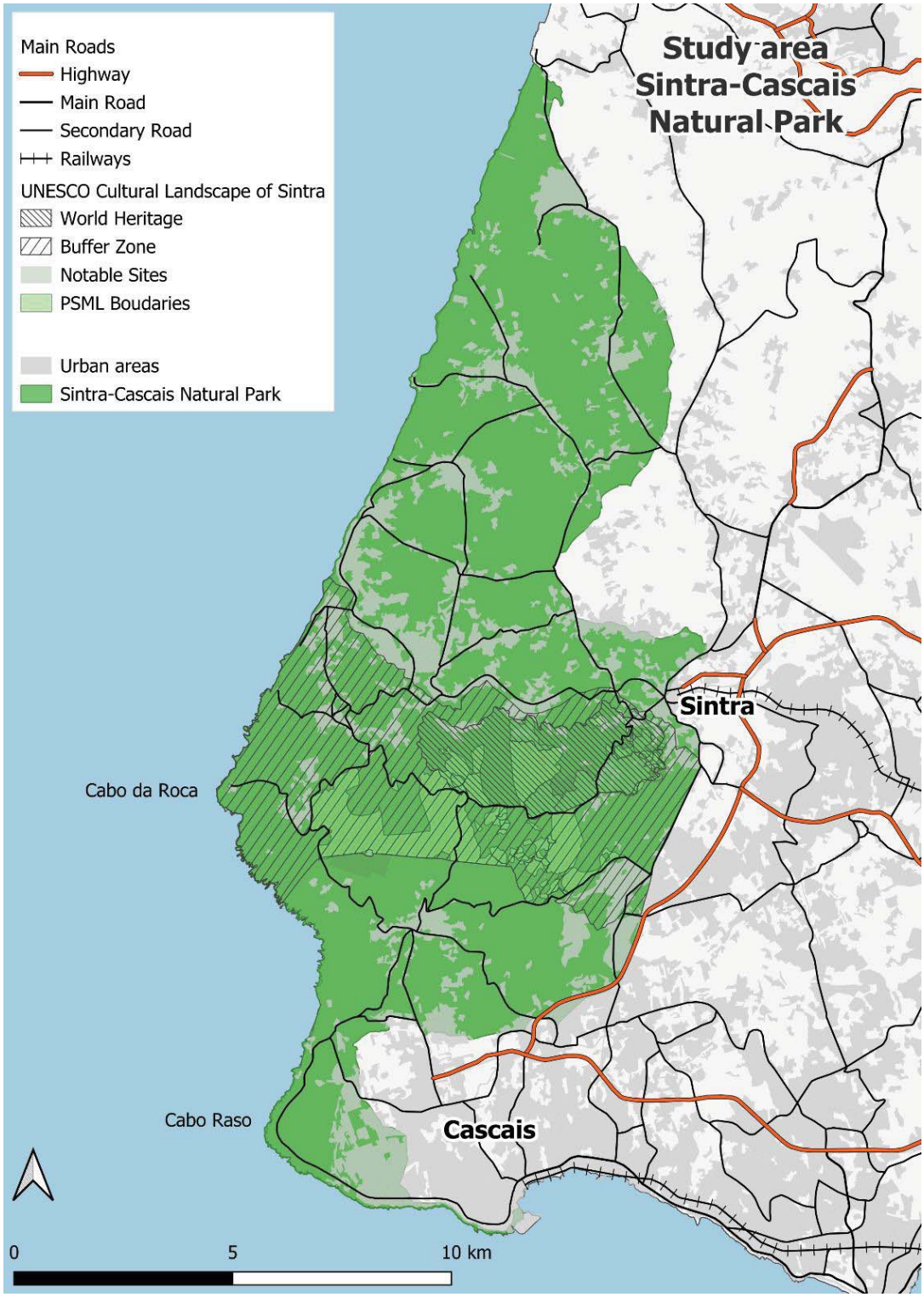

Figure 2.1 - The Sintra-Cascais Natural Park

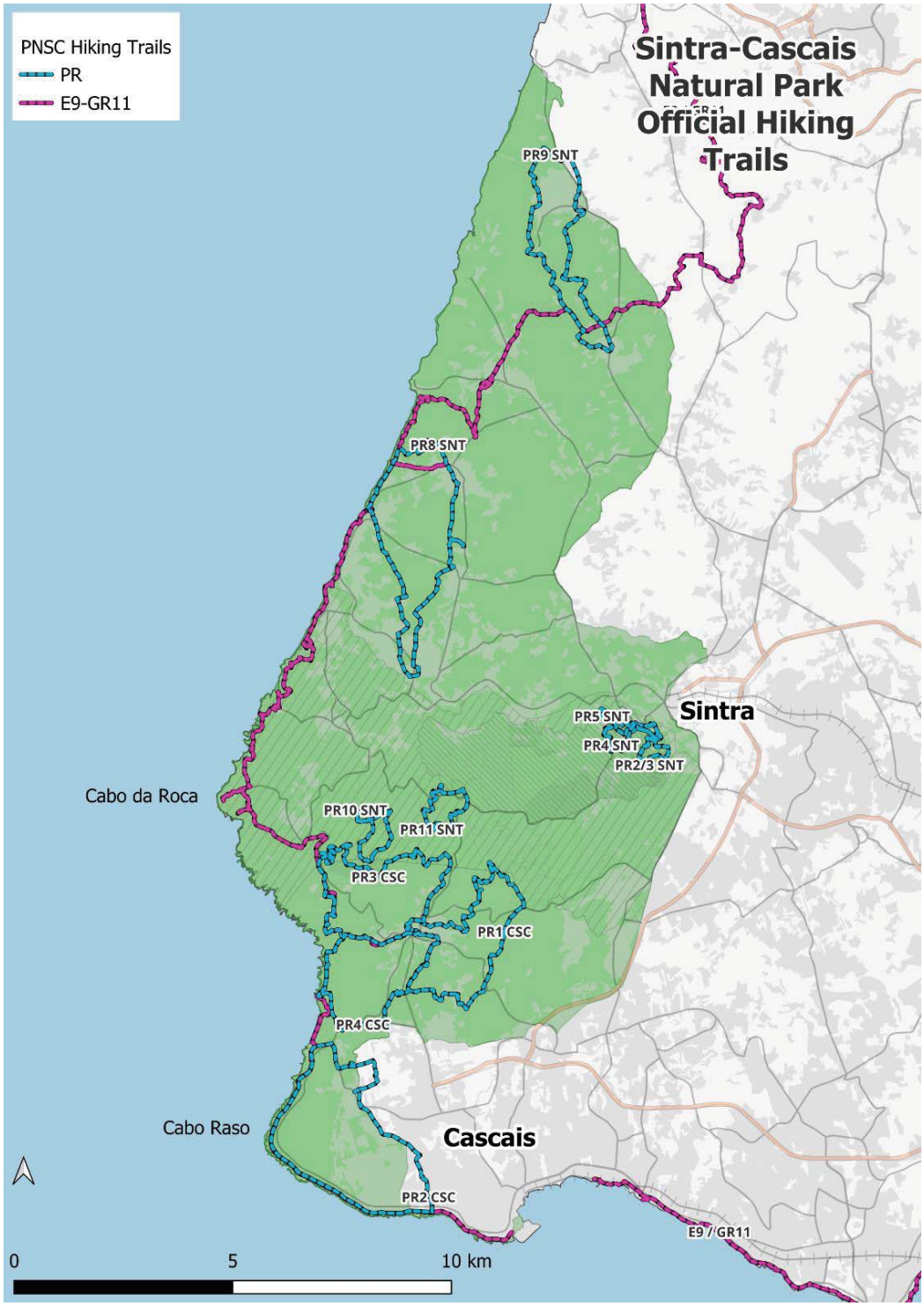

Figure 2.2 - Official Hiking Trails in Sintra-Cascais Natural Park

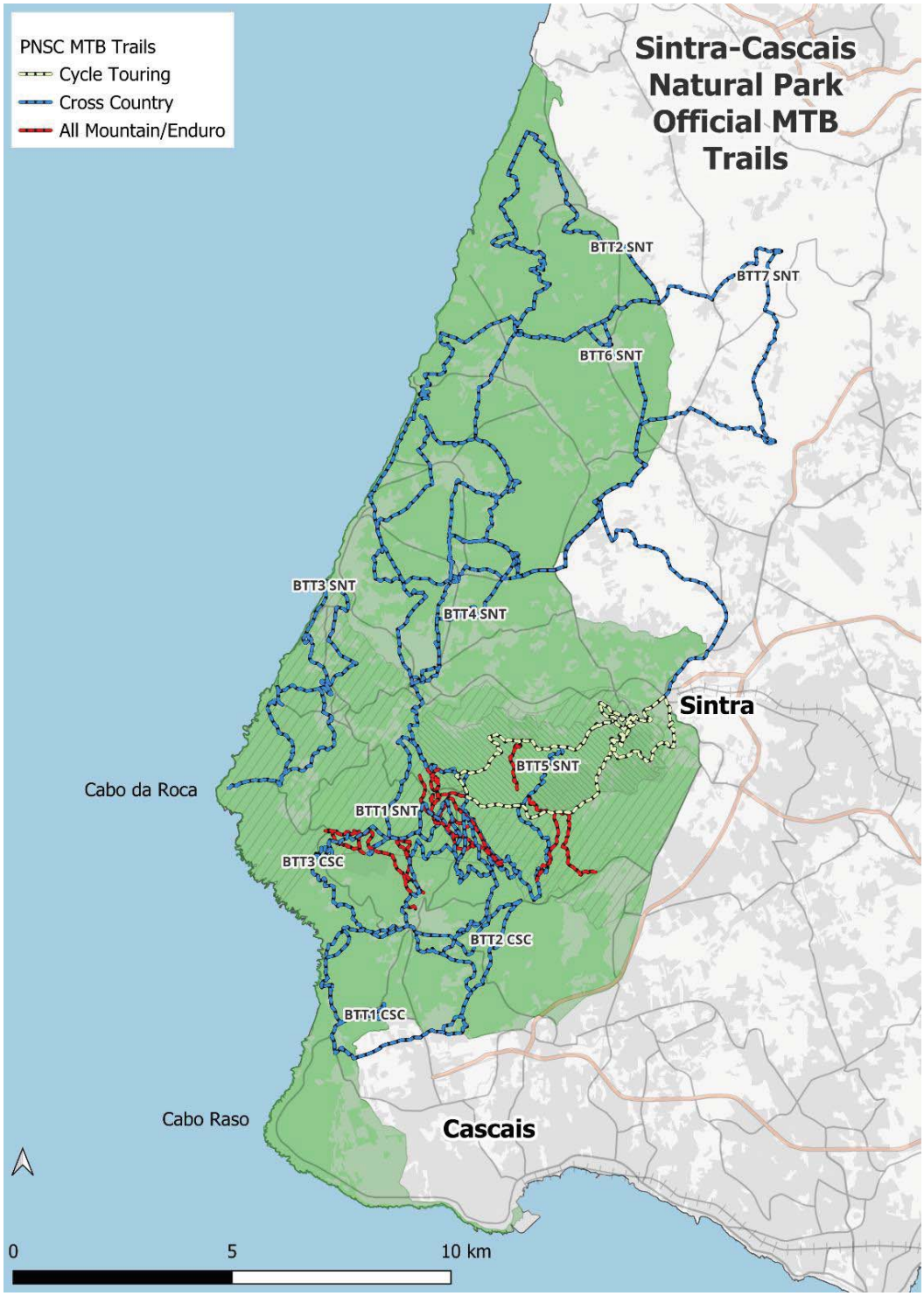

Figure 2.3 - Official mountain biking Trails in Sintra-Cascais Natural Park

Table 2.1 - Official hiking trails in the Sintra-Cascais Natural Park (PNSC) (Natural.PT, 2026)

Route	Distance (km)	Difficulty	Est. Duration	Cumulative climb (m)	Starting Point / Area
PR1 SNT Santa Maria	2	Easy	0h45	104	Praça da República, by Escadinhas (stairs) Félix Nunes
PR5 SNT Quintas	2.3	Easy	1h00	128	Largo Rainha Dona Amélia
PR10 SNT Peninha	5.9	Easy	1h40	265	Largo da Peninha
PR2 CSC Route Cabo Raso	15	Easy	3h30	203	Areia
PR3 CSC Villages Route	12.5	Easy	4h00	613	Malveira da Serra (near the church and “O farol da serra” restaurant)
PR8 SNT Wine of Colares	14.6	Medium	4h30	419	Adega Regional de Colares
PR9 SNT Villages Route	13.5	Medium	3h30	268	Largo do Coreto at São João das Lampas.
PR11 SNT Capuchos	4.9	Medium	2h00	335	Largo dos Capuchos (near Capuchos convent)
PR1 CSC Farms Route	15	Medium	4h00	457	Malveira da Serra, Rua (Street) Escola Velha, next to the fountain
PR4 CSC Guincho Coastal Route	9.6	Medium	4h00	212	Malveira da Serra near the chapel
PR2/3 SNT Pena and Mouros	4.7	Hard	2h30	331	Largo Rainha Dona Amélia
PR4 SNT Seteais	3.5	Hard	1h30	214	Largo Rainha Dona Amélia

Table 2.2. Official mountain biking trails in the Sintra-Cascais Natural Park (PNSC) (Natural.PT, 2026; Centro Cycling Janas, 2026)

Route	Distance (km)	Difficulty	Starting Point
BTT1 SNT Capuchos	31.2	Medium	Centro Cycling Janas
BTT2 SNT Rota dos Moinhos	Currently not available		
BTT3 SNT Cabo da Roca	Currently not available		
BTT4 SNT Vinho Colares	Currently not available		
BTT5 SNT Pedra Amarela	35.4	Medium	Centro Cycling Janas
BTT6 SNT Rota Rural	39.7	Easy	Centro Cycling Janas
BTT7 SNT Rural Rural II	34.3	Easy	Centro Cycling Janas
CT1 Vila de Sintra	2,5	Easy	Vila de Sintra
CT2 Palácio da Pena	7,4	Easy	Palácio da Pena
CT3 Monumentos	15	Easy	Vila de Sintra
BTT1 CSC Estreitos da Malveira	23	Medium / Hard	Capela da Malveira da Serra
BTT2 CSC Cascais Cultural	17.5	Easy	Capela da Malveira da Serra
BTT3 CSC Volta à Peninha	20	Medium	Parque de estacionamento da Peninha
BTT1 SNT Capuchos	31.2	Medium	Centro Cycling Janas
BTT2 SNT Rota dos Moinhos	Currently not available		

2.2. Data collection

The dataset for this study was obtained from two web-share services that collect volunteered geographic information (VGI) from outdoor recreationists. The first source was GPSies, which provided data for 2017, while the second was Wikiloc, from which a sample of tracks covering 2025 was retrieved. Both platforms contain user-generated GPS tracks for a wide range of recreational activities. However, for this study, only those identified as hiking and mountain biking were selected. Together, these sources

provided a database for analyzing both current recreational use and historical patterns in the Sintra-Cascais Natural Park.

Data collection for GPSies followed a systematic search, in line with methodologies established in previous research, aiming to download virtually all tracks available for the Sintra-Cascais Natural Park and its surroundings (Campelo & Mendes, 2016). At the time of data collection, the GPSies web platform allowed bulk downloads of up to 250 tracks per query, and provided filters by activity type, distance, cumulative elevation gain and other attributes. These options made it possible to retrieve a comprehensive set of GPSies tracks for the study area and to minimise selection bias for 2017.

For Wikiloc, data collection followed a different procedure due to technical limitations of the platform. Wikiloc does not provide an option to download multiple tracks at once and restricts the number of results shown in each search. Therefore, tracks were obtained through repeated searches, using the activity filters “Hiking” and “Mountain Biking” together with a geographic filter limited to routes located within the boundaries of the Sintra-Cascais Natural Park. Because of these technical limitations, it was not possible to systematically download all available tracks for the study area, as was done for GPSies. Instead, a structured sampling approach was adopted: search results were manually screened to verify spatial relevance, and selected tracks were downloaded individually in GPX format. To reduce potential bias, tracks were repeatedly sampled until a comparable number of routes (over 1,000 for each activity) had been collected. Only routes intersecting the park boundaries were retained for analysis.

While using different platforms may introduce potential biases, comparisons show that variation is greater between activities within the same year than between the same activity across platforms and years. This consistency suggests that the datasets may be comparable, and that perceived spatial patterns may be reliable despite platform changes. In addition, GPSies has since disappeared, while Wikiloc has become increasingly popular among both free and paid users, partly because it is cheaper than Strava and other sports apps. The popularity of individual web-share services changes over time, much like social media: many platforms started as collaborative wiki-style projects and later evolved into corporate services with new business models. Although such shifts can affect usage patterns, the overall digital footprint of recreational and outdoor activities remains a robust source of information for understanding how visitors use protected areas.

2.3. Data analysis

All tracks were downloaded in GPX format and imported into ArcGIS, where they were converted into shapefile format for processing. After conversion, four datasets were compiled, corresponding to the two activities (hiking and mountain biking) and the two study periods (GPSies 2017 and Wikiloc 2025).

Prior to analysis, each dataset was screened and duplicated submissions were removed.. For each track, the starting point, length, and number of vertices were calculated to assess data accuracy. Descriptive statistics including the number of tracks, minimum, maximum, and average distance, and the density of trackpoints per kilometer were produced for each dataset. These statistics were presented in a dedicated table and complemented with distance histograms, providing an overview of data quality and distribution before spatial analysis.

To assess spatial intensity in use, all tracks were projected onto a uniform 25 × 25 meter grid covering the extent of the Sintra-Cascais Natural Park. A spatial join was performed to count how many track segments traversed each cell. These results were then rasterized, producing a grid of 25 m pixels in which each pixel value reflects the frequency of use. To standardize comparison between datasets, the raw counts were reclassified into 10 intensity classes using equal-interval classification, plus a class for no use, resulting in intensity rasters ranging from 0 (no activity) to 10 (maximum activity). Separate rasters were generated for hiking and for mountain biking in each time period.

Finally, the classified rasters were compared across both time periods and activity types. This included direct comparisons of mountain biking in Wikiloc (2025) versus GPSies (2017), and hiking in Wikiloc (2025) versus GPSies (2017), as well as cross-activity comparisons within the same year (mountain biking vs. hiking for each source). This framework enabled both temporal and activity-based analyses, highlighting differences in recreational preferences, areas of overlap, and emerging potential conflict zones within the park.

3. Results

The final datasets included 1,428 mountain biking tracks and 1,385 hiking tracks from Wikiloc (2025), and 1,734 mountain biking (MTB) tracks and 276 hiking tracks from GPSies (2017) (Table 3.1). The datasets allow a general characterization of recreational routes in terms of route length and trip configuration.

Table 3.1 - Attributes of recreational tracks obtained from Wikiloc and GPSies for Sintra-Cascais Natural Park (MTB = mountain biking).

	Wikiloc		GPSies	
Statistic	**MTB**	**Hiking**	**MTB**	**Hiking**
N	1428	1385	1734	276
Mean distance (km)	32.3	22.4	53.7	31.3
Mean distance (km), 95% of track lengths	27.92	11.94	42.00	21.61
Max distance (km)	384.8	7292.2	3313.7	1117.5
Min distance (km)	1.2	0.2	0.5	0.4
Std deviation (km)	26.4	198.5	128.0	77.6
Round trip (%)	85.1 (1215)	77.1 (1068)	83.6 1450)	76.1 (210)
One way trip (%)	14.9 (213)	22.9 (317)	16.4 (284)	23.9 (66)

Overall, mountain biking routes tend to be longer than hiking routes in both datasets. Round trips predominate for both activities across both platforms. However, one-way trips are proportionally more frequent among hiking routes than among mountain biking routes. For the Wikiloc dataset, round trips were identified using a spatial criterion: routes finishing within 500 m of the starting point were classified as circular, in order to account for common GPS recording artefacts such as delayed signal acquisition at the start of a session.

Figure 3.1 shows the distribution of route lengths for the four datasets analysed in this study. Overall, all histograms are positively skewed, indicating that short and medium-length routes are much more common than very long ones. Clear differences between activities are also visible: mountain biking routes tend to be longer than hiking routes in both platforms, while Wikiloc hiking is most strongly concentrated in the shortest distance classes. GPSies mountain biking shows the broadest spread and the highest mean route length after clipping at the 95th percentile (42.00 km), whereas Wikiloc hiking has the lowest mean value (11.94 km).

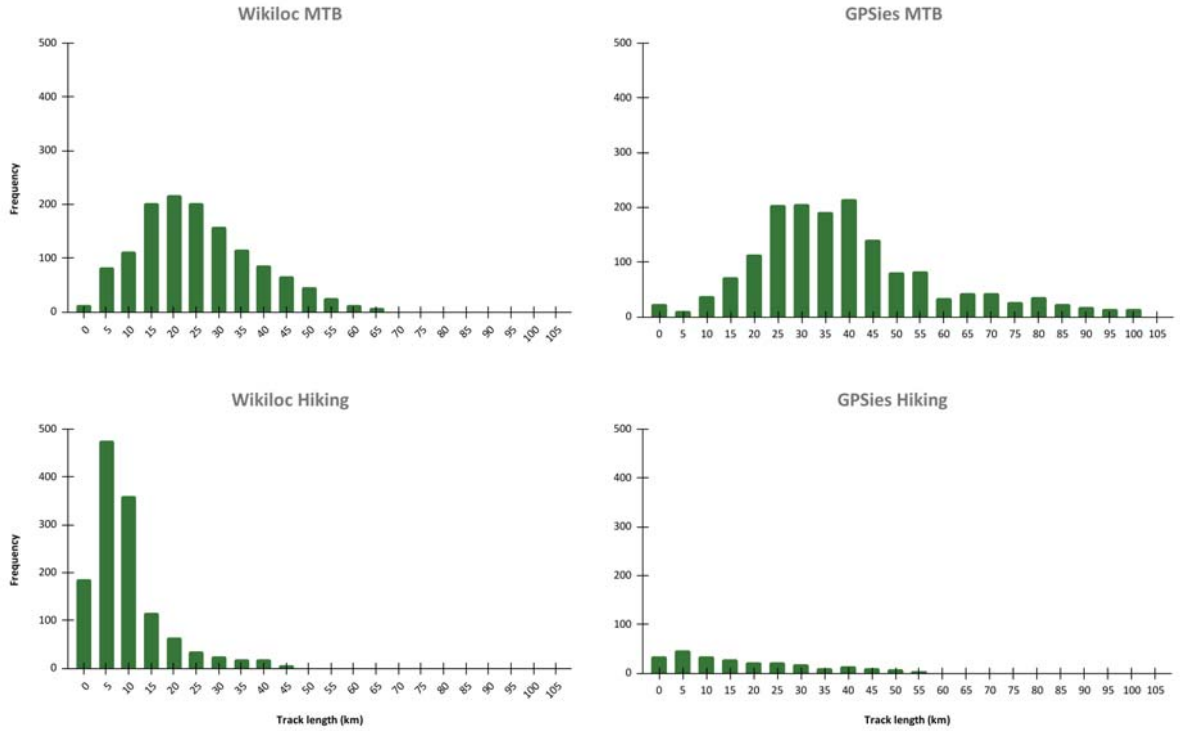

Figure 3.1 - Frequency distribution of route lengths in Wikiloc and GPSies datasets

Analysis of starting points from the GPSies 2017 and Wikiloc 2025 reveals both persistent and evolving spatial patterns of recreational use within the Sintra-Cascais Natural Park. For mountain biking (MTB), in both 2017 and 2025 the majority of routes originate along the eastern edge of the park, in close proximity to Lisbon and the surrounding urban areas (Figure 3.2). A clear intensification of mountain biking is evident by 2025, with starting points becoming more numerous and extending further along the eastern and southeastern boundaries. Compared to 2017, there was also stronger evidence of urban-based users entering the park from nearby towns and suburbs. For hiking, the 2017 dataset shows a relatively even distribution of starting points along the eastern and southern edges of the park, with fewer routes beginning in the interior (Figure 3.3). By 2025 the number of hiking routes increases substantially, with more routes originating from within the park rather than solely from its perimeter, indicating deeper exploration of the interior. In contrast to mountain biking, hiking routes in 2025 also extend toward the western and coastal areas, showing a wider spatial spread. When comparing the two activities directly, mountain biking remains more concentrated around easily accessible entry zones, whereas hiking demonstrates broader geographic coverage.

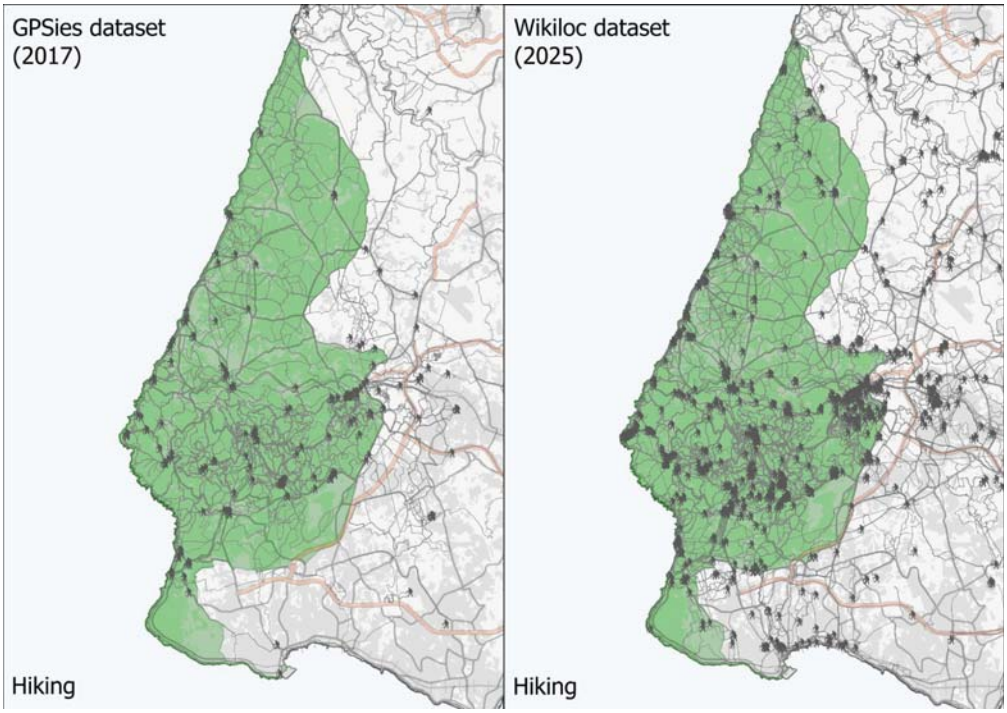

Figure 3.2 - Hiking trails and starting points in 2017 and 2025

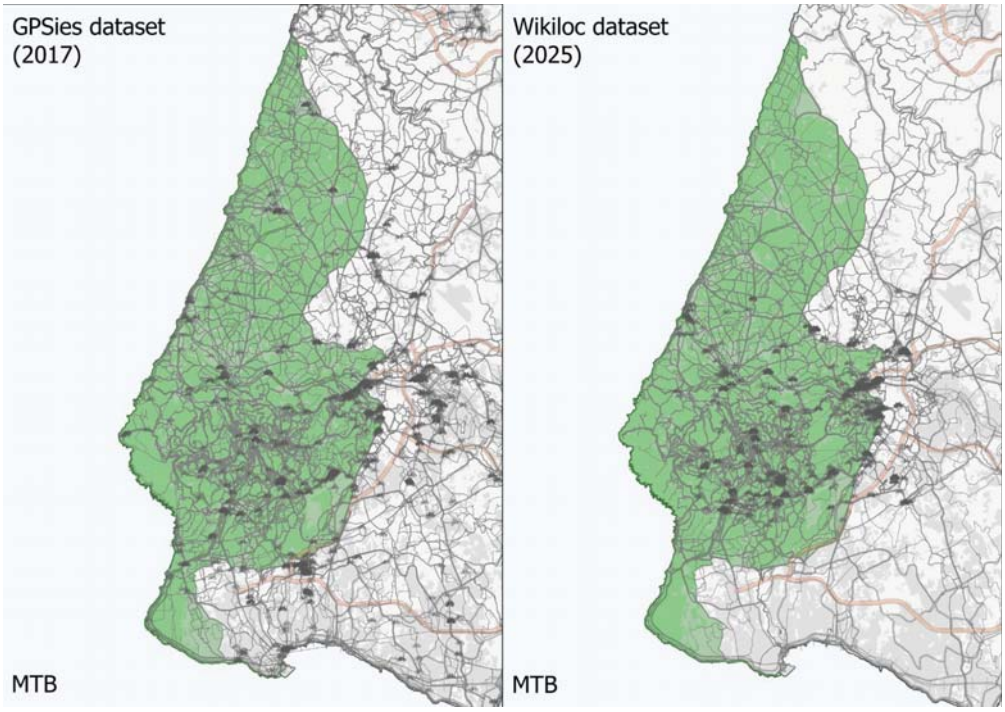

Figure 3.3 - Mountain biking trails and starting points in 2017 and 2025

A more detailed view of route distribution is presented for the areas surrounding the main castles and palaces of Sintra, as well as the Cabo da Roca coastal zone (Figures 3.4, 3.5, 3.6 and 3.7), which represent key attraction points within the park. Around the main castles and monuments, both datasets show a clear clustering of routes along the main road network and established access paths. In the 2017 GPSies data, hiking and mountain biking routes are mainly concentrated along the primary corridors connecting the central attractions. In the 2025 Wikiloc dataset, the number of routes increases noticeably, particularly for hiking, with tracks extending into secondary trails surrounding the main landmarks.
A similar pattern can be observed in the Cabo da Roca area. In 2017, routes are relatively limited and largely follow the principal access roads and coastal viewpoints. By 2025, the number of hiking routes increased and spread further along the coastal landscape and nearby trails. Notably, while some mountain biking routes appear near Cabo da Roca in the 2017 dataset, no mountain biking routes start from this location or its immediate surroundings in the 2025 Wikiloc data, with activity remaining concentrated along more accessible inland corridors.

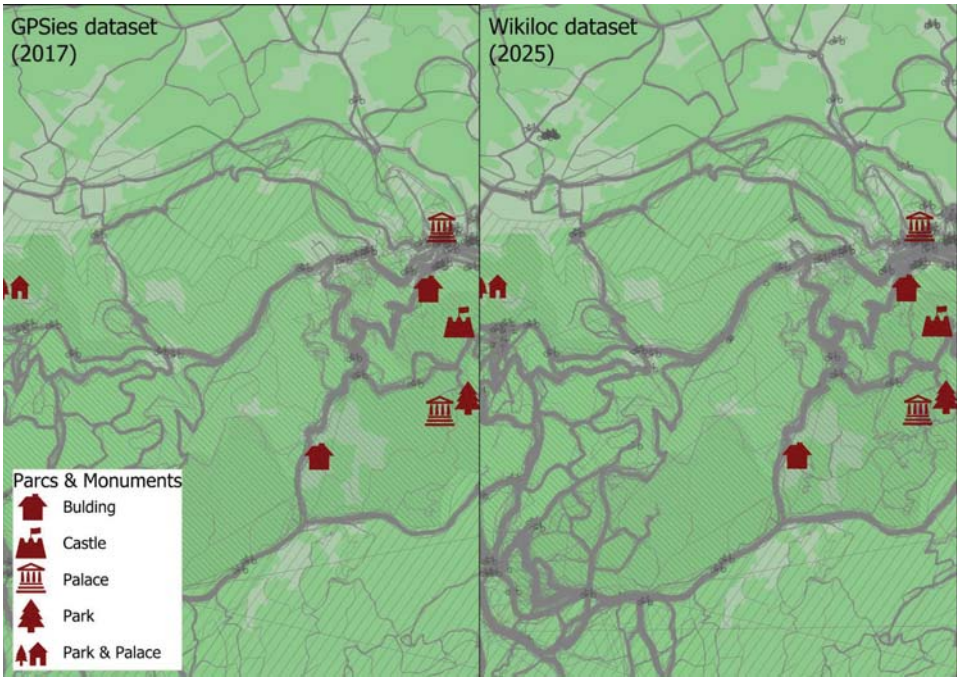

Figure 3.4 - Spatial distribution of mountain biking routes from GPSies (2017) and Wikiloc (2025) datasets around the main castles and palaces of Sintra.

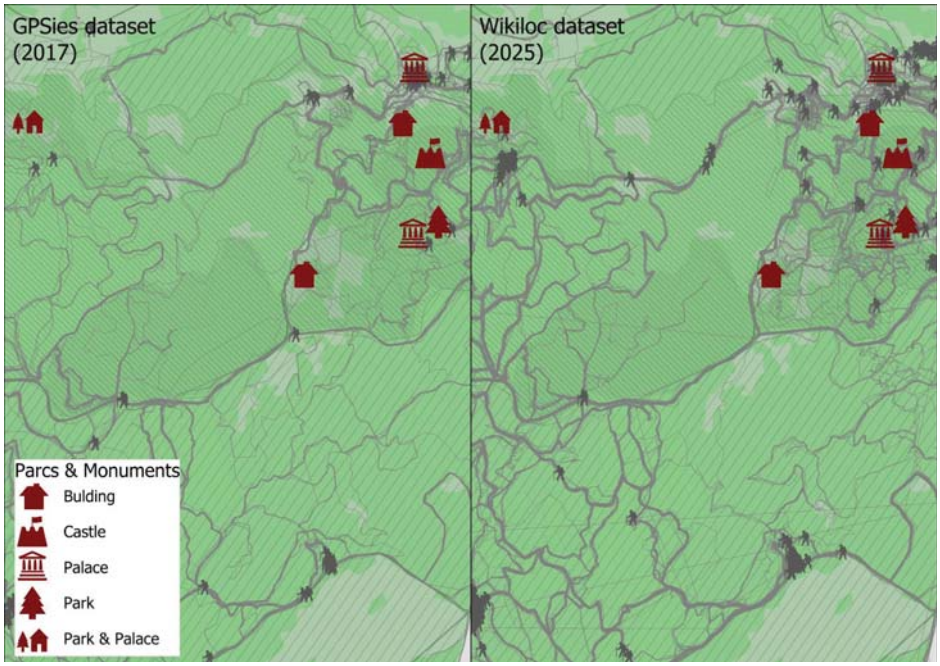

Figure 3.5 - Spatial distribution of hiking routes from GPSies (2017) and Wikiloc (2025) datasets around the main castles and palaces of Sintra.

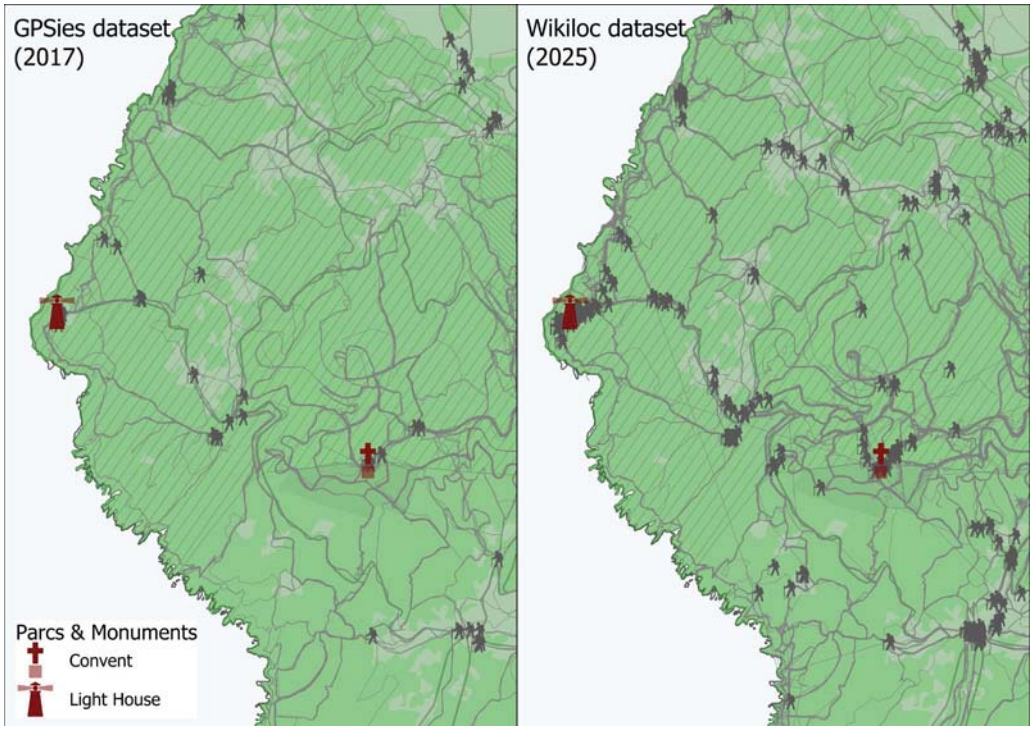

Figure 3.6 - Spatial distribution of hiking routes from GPSies (2017) and Wikiloc (2025) datasets around the Cabo da Roca.

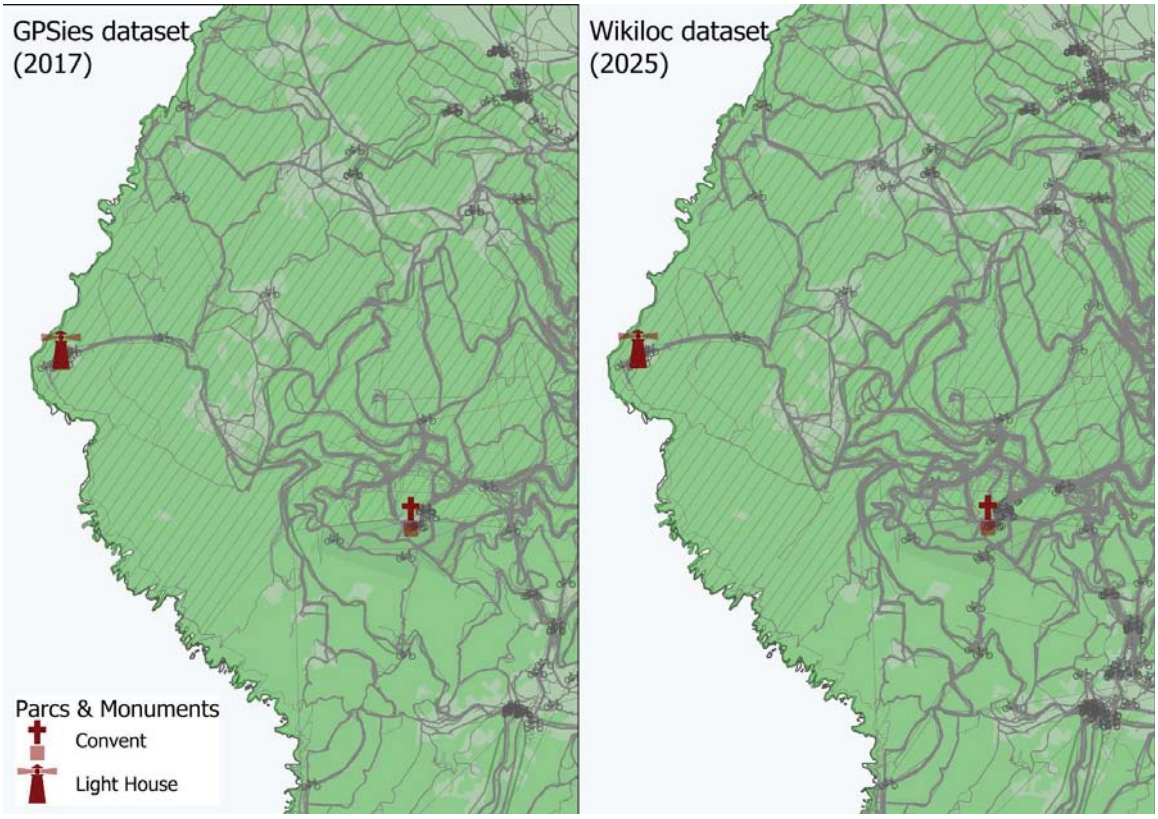

Figure 3.7 - Spatial distribution of mountain biking routes from GPSies (2017) and Wikiloc (2025) datasets around the Cabo da Roca.

The maps (Figures 3.8 and 3.9) highlight clear differences in the spatial distribution of hiking and mountain biking activities across 2017 and 2025. Darker shading indicates areas with higher numbers of recorded trails, allowing for the identification of recreational hotspots.

In 2025, hikers show a pronounced concentration of trails around the highest elevations of the Sintra mountains, especially near cultural landmarks such as Pena Palace, the Moorish Castle, and the Capuchos Monastery. Hiking routes are also strongly associated with water features and coastal areas, with dense use observed around Cabo da Roca and along seaside cliffs. Mountain biking routes in 2025 are likewise concentrated at higher elevations, but with distinct preferences. Bikers tend to avoid palace grounds and tight heritage spaces, instead favoring forest roads and rugged off-road tracks. Nevertheless, bikers also show strong use of the Capuchos Monastery area, where accessible downhill and all mountain tracks converge. In 2017, overall use intensities of users are much lower. Hiking trails were recorded far less frequently near palaces, with only a few hundred tracks documented in the GPSies dataset. The substantial increase in hiking activity visible by 2025 coincides with the broader surge in tourism to Portugal, and to Sintra in particular, over this period. This growth is reflected in the expanded trail promotion efforts of institutions such as Parques de Sintra -Monte da Lua, Visit Sintra, Visit Cascais, and Natural.PT. These organizations have developed dedicated hiking resources that direct visitors towards specific routes within the park. Mountain biking already showed patterns similar to those in 2025, with routes clustered in the high ridges and accessible dirt roads. Several routes that appear in 2025 are absent

in 2017, indicating that some paths were closed or less accessible at the time. Despite differences in use intensity, the overall spatial patterns remain consistent between 2017 and 2025.

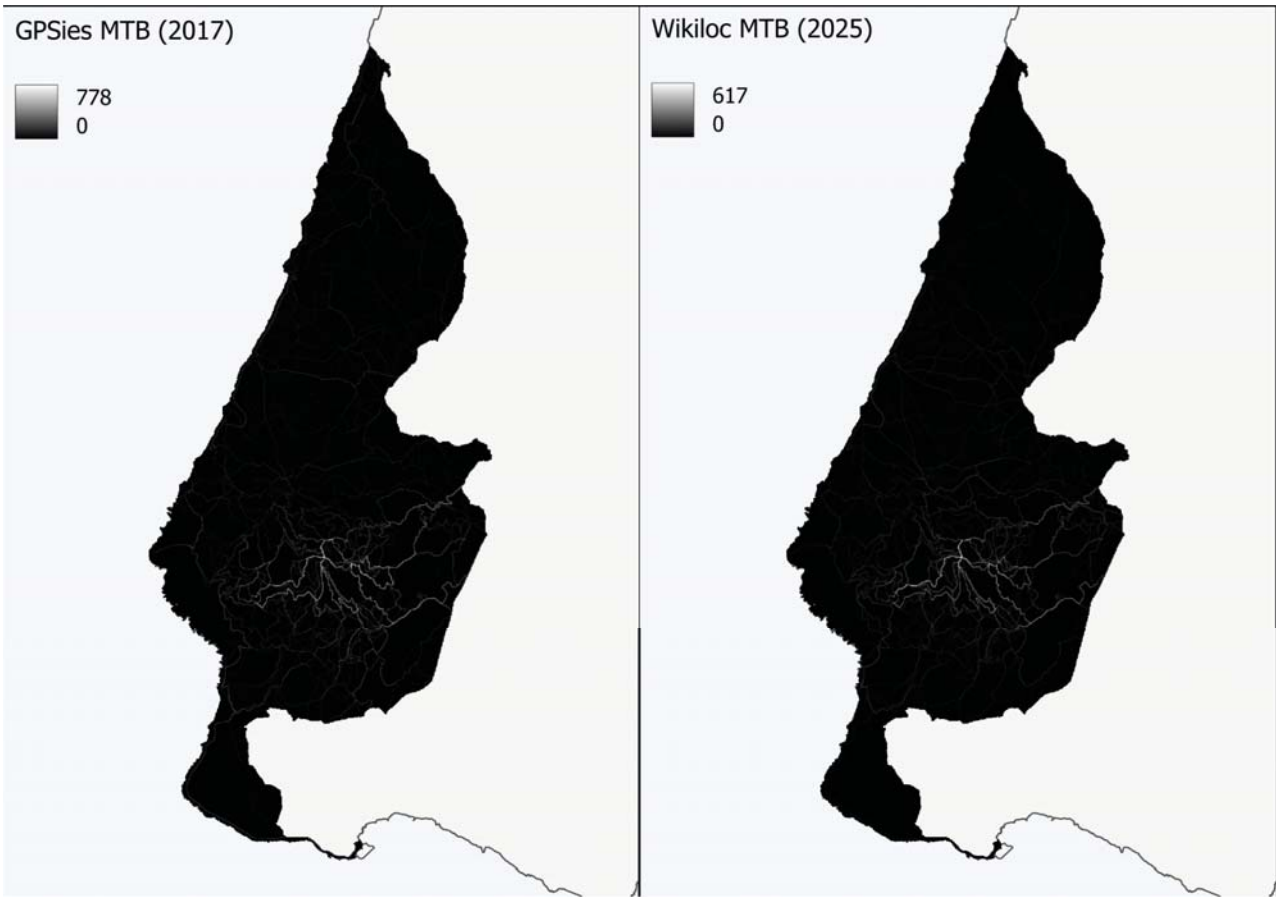

Figure 3.8 - Comparison of mountain biking trail use intensity for PNSC in 2017 and 2025.

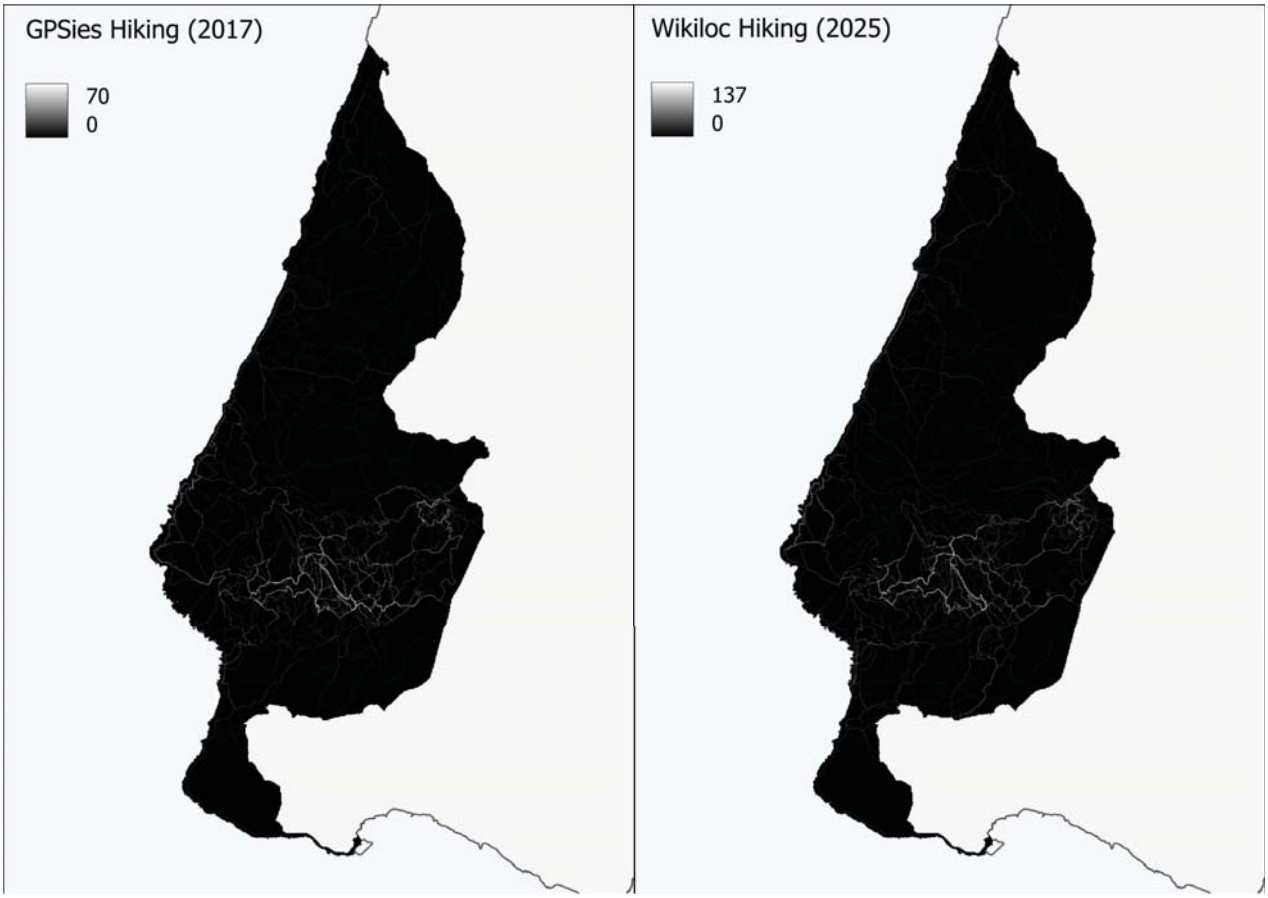

Figure 3.9 - Comparison of hiking trail use intensity for PNSC in 2017 and 2025.

The relative intensity of use and trail counts increased markedly between 2017 and 2025 (Figures 3.10, 3.11, 3.12 and 3.13). In the 2017 dataset (GPSies), only a few hundred hiking tracks were recorded, whereas mountain biking was already better represented. By 2025 (Wikiloc), the totals for both activities are substantially higher, with especially large growth evident in the top quantile of cells by use density. The highest-use zones in 2025 register much higher counts than in 2017. Despite this increase, the spatial pattern of heavily used corridors and nodes remains consistent across years, with the busiest areas in 2017 still being the busiest in 2025. Absolute levels of use increase almost everywhere. Hikers' tracks concentrate strongly along the official footpath network connecting monuments and viewpoints, for instance, routes from Sintra town up to Pena Palace and the Moorish Castle, and along the coast from Praia das Maçãs to Cabo da Roca. Mountain bikers exploit a wider network of dirt roads and single-track trails, extending more uniformly throughout the park, including rugged backcountry circuits and steep downhill runs in the western forests.

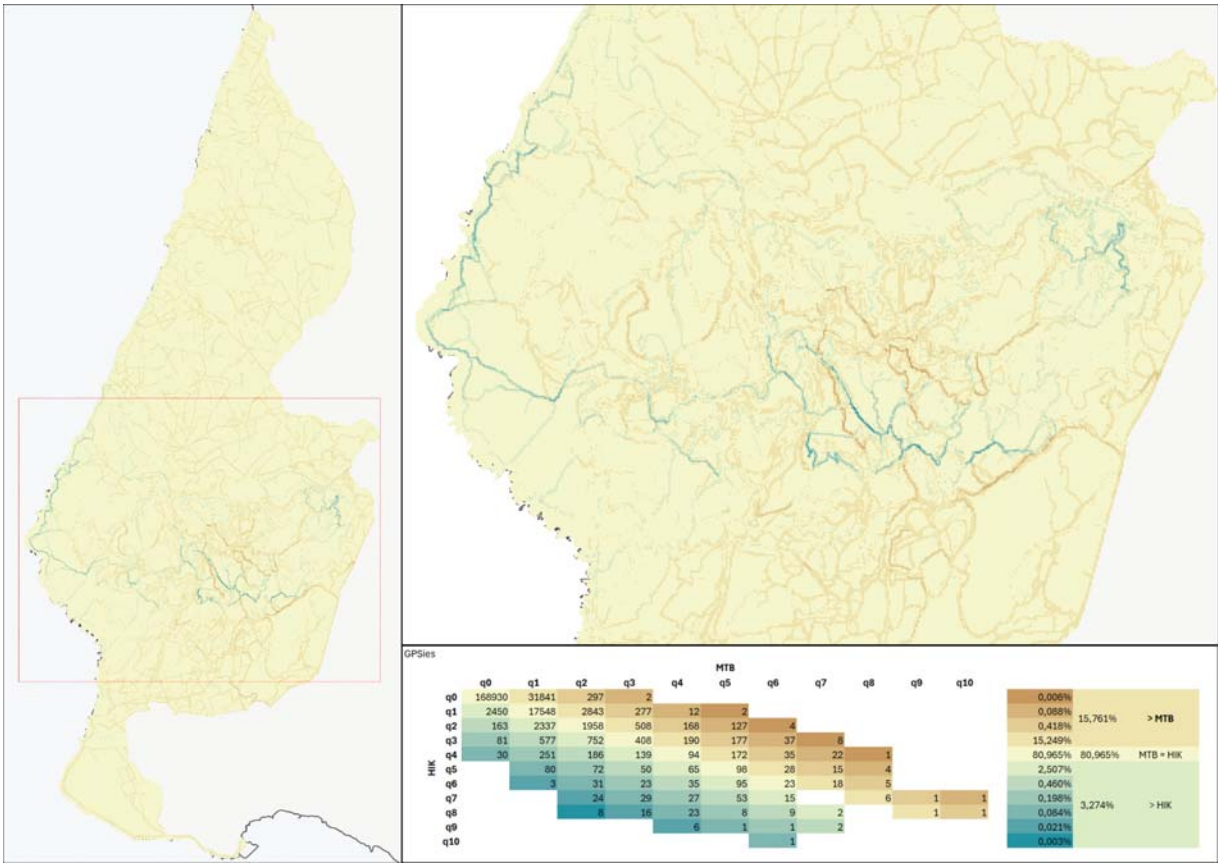

Figure 3.10 - Comparison of hiking vs mountain biking trail use intensity in 2017 (GPSies)

To compare spatial uses between hiking and mountain biking the combined analysis was used and results put on evidence differences among both activities (Figure 3.10). Although 80% of the global use is similar, by 2017 datasets there was clear evidence of the higher MTB general use and distribution as it can be seen by the nearly 16% cells where this use surpasses hiking. Higher and steepest trails for all mountain and enduro riding in the central Sintra-Cascais Natural Park are clearly seen. Trails where hiking has higher use, which happens to just 3,3% of the study area, avoid all mountain and downhill trails, and also concentrated by the coast north to Cabo da Roca where MTB can't be done.

The 2025 Wikiloc data reveal a similar overall pattern, but with a more balanced distribution between activities (Figure 3.11). MTB use still exceeds hiking in approximately 8% of cells, while hiking surpasses MTB in around 6%, which is a notably smaller gap than observed in 2017. Spatially, the shift is also visible. Hiking use is more pronounced in the vicinity of Sintra's castles and gardens, as well as along the coastal areas, reflecting the growth in heritage-oriented recreational activity. At the same time, MTB use along the steeper all-mountain trails appears comparatively reduced relative to 2017, suggesting either a contraction of the mountain biking network or a redistribution of use towards less technically demanding routes.

The cross-activity matrices comparing hiking and mountain biking intensity reveal a clear spatial separation between the two user groups. In 2017, approximately 72% of all cells (168,930 of 233,507) recorded no use by either activity (HIK = q0, MTB = q0). Cells where one activity is absent and the other present at low intensity are also common (e.g., 31,841 cells with MTB = q1 and HIK = q0; 2,450 cells with HIK = q1 and MTB = q0). Cells with high levels of use by both groups are extremely rare. Only 408 cells reached moderate intensity for both activities (HIK = q3 and MTB = q3), and fewer than 70 cells fell into the highest intensity classes (q5 or above) simultaneously. The proportion of cells where MTB intensity exceeded HIK intensity was 15.76%, while only 3.27% showed HIK exceeding MTB, with 80.97% showing equal intensity levels in both activities.

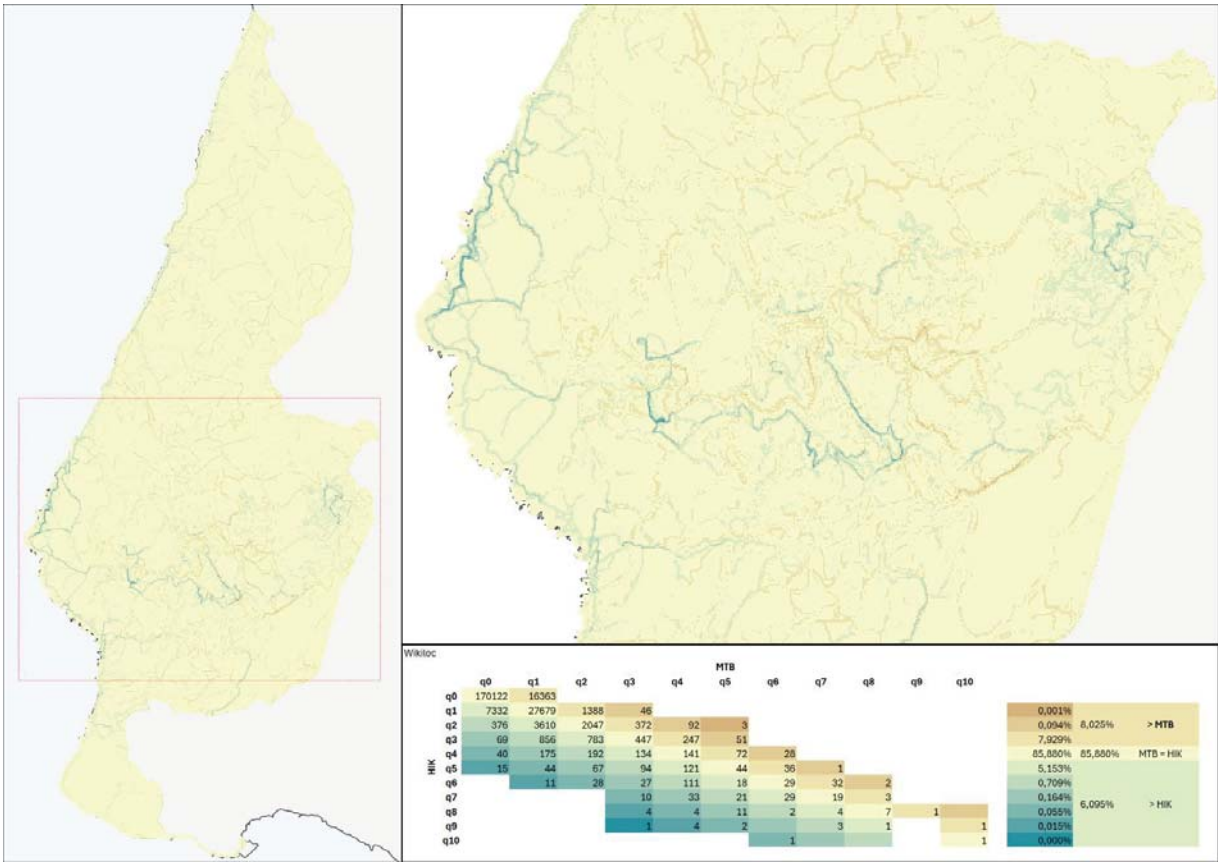

Figure 3.11 - Comparison of hiking vs mountain biking trail use intensity in 2025 (Wikiloc)

In 2025, the overall pattern remains similar. Approximately 73% of cells (170,122) still show no recorded use by either activity. However, some notable shifts can be observed. The proportion of mountain biking–dominant cells decreased (from 15.76% to 8.03%), while hiking-dominant cells increased (from 3.27% to 6.10%), reflecting the relative expansion of hiking and contraction of mountain biking across the park.

A similar pattern appears for mountain biking in 2017 vs 2025 (Figure 3.12). The cell with no recorded biking in either year (q0) contains 164,249 grid cells. The total number of cells with no recorded biking activity was 171,654 in 2017 (GPSies) and 177,954 in 2025 (Wikiloc), representing approximately

73% and 76% of all cells respectively. This indicates a slight contraction of the spatial extent of mountain biking over the study period: the number of cells with any recorded biking use declined from approximately 61,853 in 2017 to 55,553 in 2025. Notably, mountain biking reveals the most similar use patterns between both datasets, with over 87% of cells falling at identical intensity levels. This is the highest agreement observed across all activity comparisons. Cells in high-intensity classes (q8–q10) are virtually absent in both years.

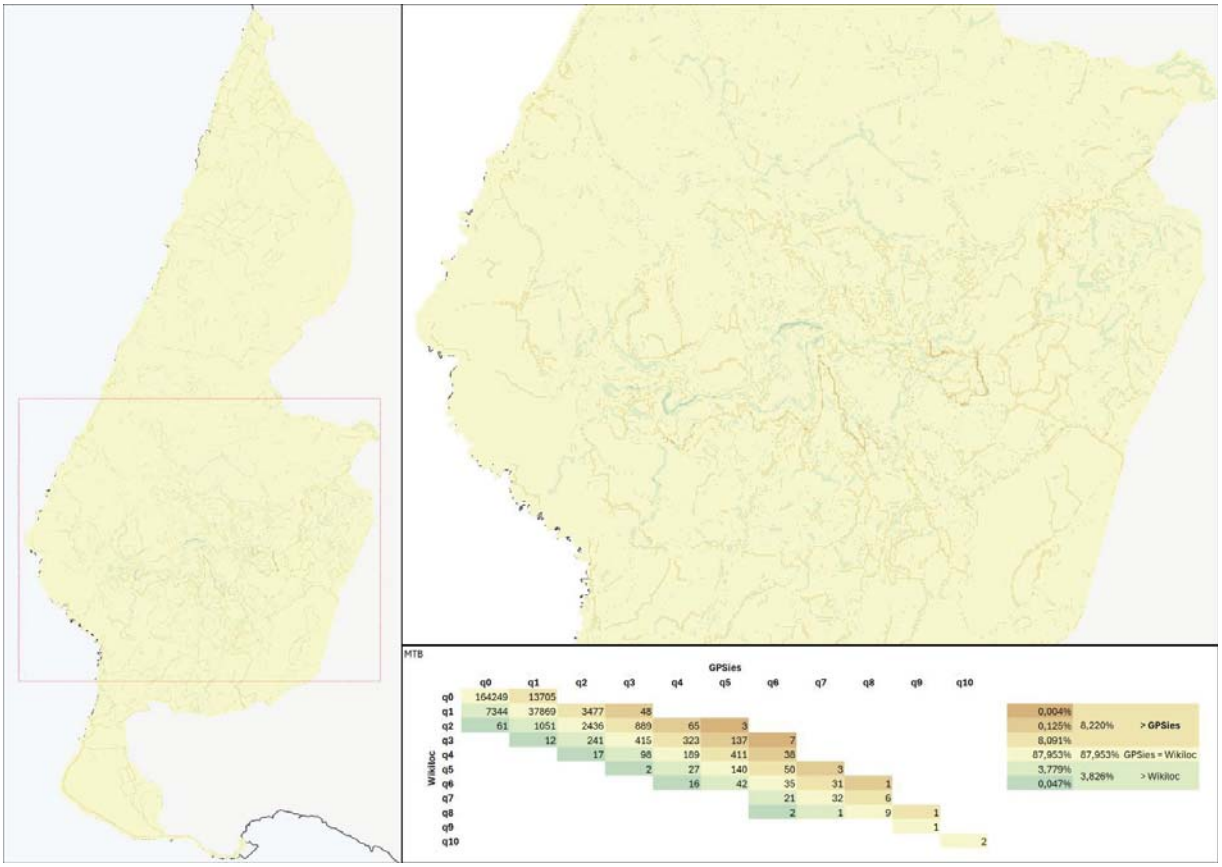

Figure 3.12 - Comparison of mountain biking trail use intensity between 2017 (GPSies) and 2025 (Wikiloc)

The overlap matrix comparing hiking use intensity between the two data sources (Figure 3.13) shows that 85.6% of all cells record identical intensity levels across both datasets. The largest single cell, where no hiking was recorded in either dataset (q0), contains 182,121 grid cells. GPSies 2017 recorded higher hiking intensity than Wikiloc 2025 in approximately 4.0% of cells, while Wikiloc 2025 showed higher intensity in around 10.4% of cells, indicating a net increase in the spatial footprint of hiking between the two periods. Cells in higher intensity classes (q6–q10) are rare in both datasets but more frequent in Wikiloc, consistent with the broader growth of hiking activity observed by 2025.

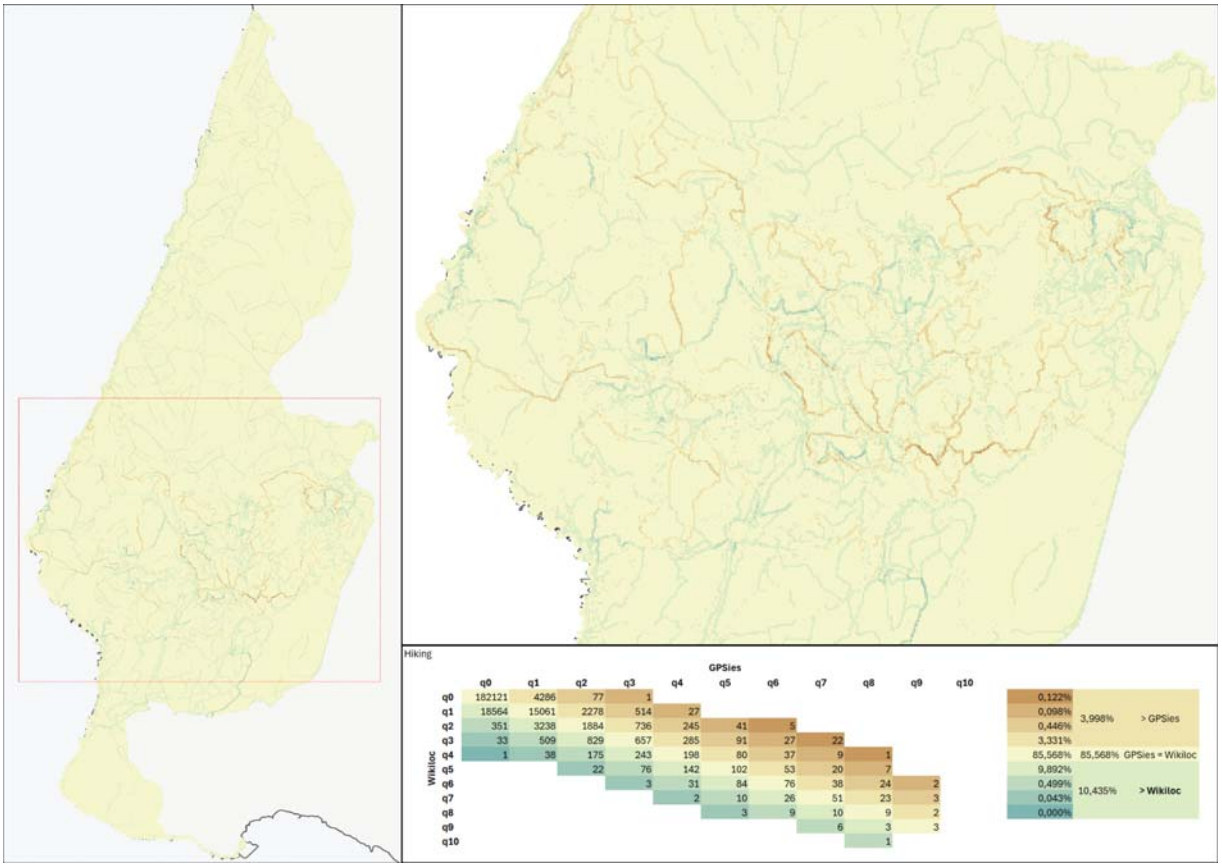

Figure 3.13 - Comparison of hiking trail use intensity between 2017 (GPSies) and 2025 (Wikiloc)

Taken together, mountain biking remained more widespread than hiking, but the difference between the two activities decreased over time, as hiking intensified around cultural landmarks and coastal areas. Importantly, the contrast between hiking and mountain biking within the same year was larger than the differences observed between GPSies (2017) and Wikiloc (2025) for the same activity, suggesting that platform-related bias is limited.

4. Discussion

This study provides a detailed spatial analysis of recreational trail use patterns in the heavily visited peri-urban protected area of Sintra-Cascais Natural Park (PNSC).

Using Volunteered Geographic Information (VGI) to characterize hiking and mountain biking activities in 2017 (GPSies) and 2025 (Wikiloc), it was possible to reveal both temporal shifts and spatial differences in recreational use between these two periods. These findings have important implications for managing visitor flows, reducing potential conflicts between user groups, and preserving ecologically sensitive areas within the park. Between 2017 and 2025, hiking activity in PNSC expanded substantially in both spatial extent and intensity. The number of recorded hiking routes increased, and hiking use grew from limited spatial coverage in 2017 to a widespread distribution across the central mountainous areas of the park, coastal zones, and areas surrounding cultural landmarks by 2025.This expansion reflects broader trends observed in peri-urban protected areas worldwide, where growing urban populations increasingly seek accessible nature-based recreation close to their places of residence (Arnberger & Brandenburg, 2007; Rossi, Byrne, & Pickering, 2015). Similar patterns have been documented in other European peri-urban parks, where hiking activity has increased, particularly around heritage sites and scenic viewpoints, driven by improved trail infrastructure, enhanced digital connectivity, and increased promotion through social media and GPS tracking platforms (Heikinheimo et al., 2017; Korpilo, Virtanen, & Lehvävirta, 2017). There was a concentration of hiking routes around Pena Palace, the Moorish Castle, and Cabo da Roca showing that visitor activity is highest near major landmarks and key access points. This pattern is reinforced by the active role of Parques de Sintra - Monte da Lua in managing and promoting access to these sites, as well as by the significant growth of tourism in Portugal over the last decade, which has substantially increased visitor flows to Sintra and its surrounding natural areas. Similar patterns are commonly observed in protected areas, where recreational use tends to cluster around popular attractions and well-developed infrastructures (Balmford et al., 2015; Pickering et al., 2018). A comparable spatial distribution was reported by Norman and Pickering (2017) in Lamington National Park (Australia), where hiking activity was concentrated near main entry points and tourist sites and declined with distance from these locations.

In contrast, mountain biking showed relatively stable spatial patterns over the study period. Although the total number of biking routes remained high, the spatial extent of mountain biking decreased slightly between 2017 and 2025. Instead of expanding into new areas, riders appeared to concentrate around a few preferred circuits. This pattern, highly differentiated from the trends observed for hiking, may be explained by several factors. Mountain bikers often prefer established trails with technically challenging terrain (Mendes et al., 2023), which are not widely available across Sintra-Cascais Natural Park (PNSC). In addition, many informal mountain bike trails may have already been developed before 2017. Besides that, increased hiking activity in previously shared areas may have also influenced riders to focus on specific routes only. Similar patterns have been reported in other Portuguese protected areas and other metropolitan recreational landscapes, with mountain biking expanding rapidly at first but later stabilizing around a set of preferred circuits (Campelo & Nogueira Mendes, 2016; Nogueira Mendes et al., 2012).

In addition to the observed spatial stabilization of biking activity, the results also suggest a relative decline in its intensity compared to hiking within the Serra de Sintra. This contrast may reflect not only differences in spatial preferences but also broader behavioral changes among recreational users. One possible reason is that mountain bikers are being displaced by the growing number of hikers, particularly

in shared or easily accessible areas. As hiking becomes more widespread and increasingly concentrated around key trails and landmarks, bikers may seek alternative locations away from the park center, or even outside PNSC where crowding and user conflicts are lower. Another complementary explanation relates to changes in recreational trends. Research on nature sports in Portugal documents significant growth in trail running in recent years, describing it as a rapidly expanding activity across Portuguese protected areas (Valente, 2019). This broader trend suggests that some individuals who previously engaged in mountain biking may be diversifying or shifting toward other outdoor activities. In particular, trail running offers flexible access, requires less equipment, and is more compatible with increasingly crowded trail environments (Valente, 2019).

Together, these dynamics point to a potential transition in the composition of recreational users in peri-urban protected areas. This shift has important implications for trail planning and management, as it highlights the need to consider not only spatial conflicts but also changing user preferences over time.

Another important finding is the extensive informal mountain biking network extending well beyond the official trail system. The VGI data reveal kilometers of unofficial routes, many crossing sensitive habitats and areas designated for nature protection. This pattern reflects a common dynamic in peri-urban protected areas worldwide: as recreational demand intensifies, users create informal trails to access desired destinations, escape crowding, or seek novel experiences (Leung & Marion, 2000; Wimpey & Marion, 2011). Nogueira Mendes et al. (2023) confirm that PNSC is the park within the Lisbon Metropolitan Area where informal trails and trail impacts from mountain biking are most visible and most frequently reported by managers and rangers. The growth of informal trails creates a clear management challenge. On the one hand, these trails can damage the environment by fragmenting habitats, increasing erosion, disturbing wildlife, spreading invasive species, and making it harder to enforce park regulations (Ballantyne et al., 2014; Barros et al., 2013). On the other hand, trying to close all informal trails is often ineffective if the underlying demand for access is not addressed. In such cases, users may simply create new paths elsewhere, and strict restrictions can lead to conflict between park authorities and visitors.

International experience suggests several strategies for managing informal trail proliferation. High-use informal trails with relatively low ecological impact can be formally incorporated into the trail network, upgraded with sustainable design principles, and actively maintained. This is an approach that recognizes user preferences while directing activity away from more sensitive areas (Marion et al., 2016). In PNSC, heavily used mountain biking routes identified through VGI analysis could be considered for formalization. In particular, loop routes may help reduce pressure on narrow mixed-use trails. At the same time, redundant informal trails and those located in ecologically sensitive areas should be actively closed. This can be done through physical barriers, revegetation, and clear signage, supported by enforcement during peak periods. Effective closure also requires clear communication with users and the provision of alternative routes that meet their needs. Alongside physical measures, involving mountain biking clubs and other user groups in planning, maintenance, and monitoring can improve compliance and encourage a sense of responsibility. Participatory approaches, such as GIS-based tools, have been shown to reduce conflicts and improve environmental outcomes in park settings (Wolf et al., 2015). Finally, establishing clear spatial zones with different permitted uses and management approaches can help guide visitors toward appropriate areas. However, this requires effective signage, accessible maps, and regular review based on monitoring data (Eagles et al., 2002). The low spatial overlap between hiking and mountain biking is a key finding with direct implications for management of Sintra-Cascais Natural Park (PNSC). Less than 5% of cells showed high-intensity shared use by both hikers and bikers, indicating these user groups tend to use different parts of the trail network and have different route preferences. Hikers are

more often associated with scenic trails and routes that pass cultural landmarks, typically with moderate slopes, whereas mountain bikers tend to concentrate on technical single-track trails, fire roads, and forest circuits with steeper terrain (Norman & Pickering, 2019; Pickering et al., 2010). Nevertheless, where overlap does occur, notably along the central ridge connecting Sintra village to Pena Palace, routes accessing the Convento dos Capuchos, and coastal corridors near Cabo da Roca, the potential for user conflicts increases. Indeed, research on multi-use trails shows that conflicts depend not only on how often users encounter each other, but also on factors such as speed differences, trail width, visibility, user expectations, and behavioural norms (Santos et al., 2016; Tumes, 2007). In PNSC, several mixed-use segments follow relatively narrow trails with limited visibility. These conditions can increase perceived crowding and raise safety concerns, particularly during peak visitation periods.

The zones with overlap used by hikers and mountain bikers in PNSC require targeted management interventions, for reducing conflicts between user groups. These measures may include spatial zoning that separates activities across different trails, temporal regulation such as scheduled access or one-way circulation, improvements in trail design (for example wider passing areas or better sight lines), clear signage promoting trail etiquette, and enforcement of restrictions in environmentally sensitive areas (Moore, 2004; Wolf et al., 2018; Monz et al., 2010).

Because the PNSC functions both as a Natural Park and a UNESCO World Heritage Cultural Landscape, management strategies must balance recreational access with conservation goals and the protection of cultural heritage. Several practical recommendations emerge from this study. First, targeted signage and wayfinding should be strengthened along heavily used corridors, shared by hikers and mountain bikers, as the central ridge and the main access routes leading to Pena Palace. This could help reduce congestion and user conflicts, in line with previous studies showing that interpretive signage combining behavioural guidance with information about ecological sensitivity and cultural significance can effectively influence visitor behaviour (Kidd et al., 2015). Second, designated single-use trail segments could be considered on the most heavily used routes, particularly those accessing palace grounds where narrow paths and high pedestrian volumes create safety risks for mixed use. Evidence from other protected areas shows that clearly marked activity-specific trails may help reduce perceived conflicts in heavily shared corridors (Monz et al., 2010; Pickering et al., 2011). Third, trail maintenance and erosion control should focus on high-use routes that already show signs of degradation, especially on slopes exceeding 15% gradient where soil compaction and trail incision are most pronounced, and the extensive informal mountain biking network, including trails crossing sensitive habitats. Selective formalization of heavily used routes combined with the restoration and closure of redundant and environmentally sensitive informal trails may reduce overall visitor impacts while improving visitor experience (Ballantyne & Pickering, 2015; Wimpey & Marion, 2011). Finally, visitor capacity management may become necessary on the most congested trails during peak use periods. Potential tools include timed entry systems, group size limits, and permit requirements. Although defining carrying capacity thresholds in mixed natural–cultural landscapes is challenging, further analysis of VGI data can provide a useful baseline for monitoring visitation trends and identifying when management intervention becomes necessary (Wolf et al., 2018).

Beyond managing user conflicts, PNSC faces significant challenges in protecting ecologically sensitive zones from recreational impacts. The park encompasses several habitat types classified as conservation priorities under the Natura 2000 network, including coastal dune systems with endemic vegetation, Mediterranean sclerophyllous forests, and riparian corridors supporting rare and endemic species (European Environment Agency, 2024; Soares et al., 2016).

The dune systems near Guincho Beach represent one of the most fragile ecosystems in the park, providing critical habitat for endemic plant species and specialized dune-adapted insects (Câmara Municipal de Cascais & ICNF, 2024). These systems are highly vulnerable to trampling, with vegetation damage occurring even under light recreational use. Management recommendations include maintaining boardwalk infrastructure to confine foot traffic, seasonal closures during plant reproduction periods, enhanced interpretive signage explaining dune ecology and fragility, and active restoration of trampled areas through native plant reintroduction. Riparian zones and seasonal watercourses crossed by mountain biking routes identified in the VGI data provide essential habitat connectivity and support moisture-dependent endemic species. These zones are particularly vulnerable to trail erosion and sedimentation, which can degrade water quality and aquatic habitats (Fowler & Collin, 2000). Natural engineering techniques, including bioengineered trail crossings and vegetated buffer restoration, offer nature-based solutions consistent with the park's conservation mandate.

The serra hosts remnant stands of native *Quercus* species (*Q. suber, Q. robur, Q. pyrenaica*) that represent significant ecological and cultural heritage values. The forest managed within the PNSC World Heritage Site area comprises these native species alongside more than 200 exotic species introduced in the 19th century, many of which have become invasive, most notably *Acacia melanoxylon*. Forest management by Parques de Sintra-Monte da Lua (PSML) has focused on the gradual removal of invasive and undesirable species and their replacement with native broadleaved species as a core conservation objective (Soares et al., 2016). These forest cores support specialised fauna and maintain the traditional landscape aesthetics central to the UNESCO World Heritage designation, but face pressure from invasive species, altered fire regimes, and recreational trampling. Zoning strategies should prioritise protection of these forest cores, potentially designating some areas as restricted zones with minimal infrastructure and limited mountain biking access.

The challenge of balancing public access with conservation in ecologically sensitive areas is not unique to PNSC. Similar challenges have been documented in other European cultural landscapes, where recreational pressure threatens fragile ecosystems even as visitation generates economic benefits and public support for conservation (Cullotta & Barbera, 2011; Plieninger et al., 2015). Adaptive management frameworks that integrate continuous monitoring, stakeholder engagement, and flexible response mechanisms offer the most promising approach for navigating these trade-offs.

Taken together, the challenges identified in this study, such as user conflicts, ecological sensitivity, and the spread of informal trails, are not separate issues. Instead, they represent interconnected aspects of a broader management challenge in PNSC. The park’s dual designation as a Natural Park and a UNESCO World Heritage Cultural Landscape adds further complexity. Management decisions must balance biodiversity conservation, cultural heritage protection, and the need to provide high-quality recreational experiences for a large and diverse urban population. Few comparable sites operate under such multiple and overlapping objectives. As a result, standard visitor management approaches need to be adapted to the specific ecological and institutional context of PNSC. Addressing these challenges will require more than infrastructure improvements or zoning measures alone. It will also depend on ongoing engagement with recreational users, continuous ecological monitoring, and the ability to adapt management strategies as visitation patterns change over time.

5. Conclusion

This dissertation has examined patterns of hiking and mountain biking in the Sintra-Cascais Natural Park through the analysis of volunteered geographic information. By comparing two temporal snapshots, 2017 and 2025, the study has revealed both continuity and change in the spatial dynamics of recreation. While mountain biking displayed relative stability, with activity concentrated along ridge-top and forested routes, hiking expanded considerably in scale and distribution, particularly around cultural landmarks and coastal areas. The analysis has also demonstrated that areas of overlap between activities remain limited, though moderate zones of shared use are present and require attention. Importantly, the persistence of high-use corridors across both years underscores the predictable concentration of visitation in certain scenic and heritage-rich locations. These insights highlight that, even as digital platforms and user behavior evolve, core recreational patterns within the park remain consistent.

Beyond documenting spatial intensity, this dissertation contributes a methodological framework that integrates user-generated GPS data with spatial classification to evaluate intensity and overlap. The approach demonstrates the value of crowdsourced information for understanding recreation in peri-urban protected areas, offering a replicable and cost-effective tool for managers.

Importantly, this research further confirms that VGI data can provide meaningful insights into outdoor recreational uses. Moreover, even when different datasets and data sources are employed, consistent spatial patterns can be identified and used to characterize and monitor recreational activity. While long-term monitoring would benefit from consistent and continuous data sources, this is not yet fully achieved with VGI. At the same time, the rapid growth of web-sharing platforms and sports applications has significantly increased the volume of publicly available user-generated data. As a result, even data from different sources, as long as they include a sufficient number of records, can be useful for monitoring recreational use in protected areas.

Overall, the findings emphasize the need for proactive, spatially informed management that can balance high recreational demand with ecological and cultural conservation. By aligning infrastructure, zoning, and visitor guidance with observed use patterns, the Sintra-Cascais Natural Park can continue to provide high-quality recreational opportunities while safeguarding the integrity of its landscapes and heritage.

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