

Impacts of nature-based activities on biodiversity

Deliverable 1.2.1

Version 1.0

20/02/2026

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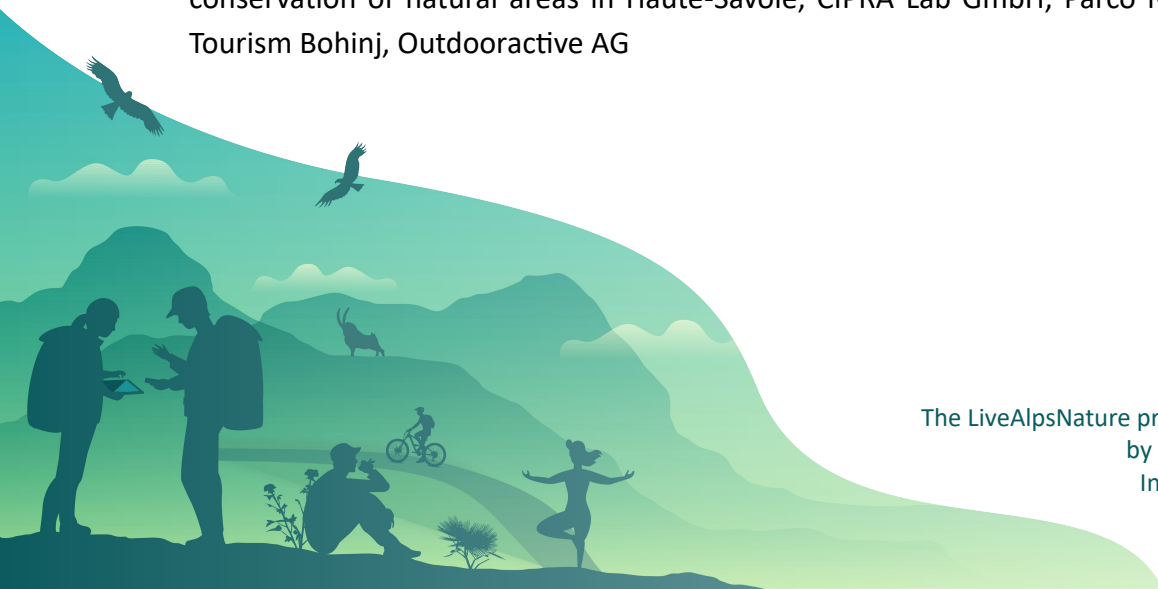


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1 Literature review on the impacts of nature-based activities on biodiversity

1.1 Introduction

The impact of outdoor activities is becoming an increasingly important issue for Alpine protected area managers, especially due to the growing popularity of these practices. The LiveAlpsNature project aims to relieve pressure on natural sensitive regions by developing new visitor management concepts and recreational offerings. Activity 1.2 deals specifically with defining the impacts of nature-based activities (NBAs) on biodiversity and habitat fragmentation. Section I presents a non-exhaustive review of scientific literature addressing these aspects, in general terms, for specific activities and seasons, as well as possible management measures to limit them. Section II examines four case studies from protected areas participating in LiveAlpsNature, with a focus on the Parco naturale Mont Avic (Italy). Section III concludes by discussing the compatibility of outdoor activities with the mission and the different protection status of protected areas.

The study by Lavorel et al. (2020) clearly frames the issue of the present work in the global context (to access citations within the text, please refer to footnotes):

One third of the world's protected areas are submitted to intense human pressure [...] (Jones et al., 2018)¹. The missions of protected areas are nature protection, with additional goals of access and education to nature. As such they are hotspots of non-material contributions to people (Diaz et al., 2018)², or cultural ecosystem services (Millennium Ecosystem Assessment, 2003)³. Protected areas are more attractive for nature tourism when they have greater biodiversity (Arbieu et al., 2018; Chung et al., 2018; Siikamaki et al., 2015)⁴. This attraction is mostly linked to iconic plant and animal species: species which are important to cultural identity through existence, aesthetic or spiritual values. [...] Iconic species provide important non-material contributions to people of learning and inspiration, physical and psychological experiences through recreation and other nature activities and to supporting identities (Cox

¹ Jones et al., 2018 <https://doi.org/10.1126/science.aap9565>

² Diaz et al., 2018 <https://doi.org/10.1126/science.aap8826>

³ Millennium Ecosystem Assessment, 2003 <https://www.millenniumassessment.org/en/index.html>

⁴ Arbieu et al., 2018 <https://doi.org/10.1016/j.ecoser.2017.11.006>

Chung et al., 2018 <https://doi.org/10.1016/j.ecoser.2018.09.004>

Siikamaki et al., 2015 <https://doi.org/10.1007/s10531-015-0941-5>

and Gaston, 2018; Diaz et al., 2018; Rüdusser et al., 2019; Subroy et al., 2019)⁵. As such they are considered as part of fulfilling protected areas goals of biodiversity conservation, psychological experiences and education and supporting identities. At the same time, recreation and tourism can have detrimental impacts on protected ecosystems and biodiversity including iconic species, especially through physical damage to soils and vegetation and through interference with fauna (Baker and Leberg, 2018; Geffroy et al., 2015; Monz et al., 2013)⁶. The two missions of nature protection and supporting education, recreation and tourism are thus complementary but can also be conflictual, creating synergies and trade-offs addressed by zoning and management plans. These tensions can be particularly acute given the economic weight of tourism in regions with highly demanded natural assets such as mountains.

In their bibliometric review on protected areas and tourism Silva et al. (2023) further stress this tension. Nature-based tourism represents about 20% of the global tourism market, with protected areas around the world accounting for approximately 8 billion visits and USD 600 billion per year. Given the growing interest in visiting protected areas, which surged in particular during the COVID-19 pandemic, the need to find a balance between their core mission of nature conservation, access to enjoyment and education, and support to regional economic development is increasingly urgent. The recent evolution of outdoor recreation across the Alps has been analysed by the LiveAlpsNature project through Activity 1.1 (see D1.1.1 – LiveAlpsNature). This deliverable D1.2.1 explores the specific ways in which nature-based activities impact wildlife and vegetation as a crucial step toward designing and implementing effective management measures and pro-environmental offers.

1.2 General impacts of nature-based activities on biodiversity

Outdoor activities affect biodiversity in many direct and indirect ways. Direct impacts include disturbance or killing of wildlife, and harvesting and trampling of vegetation; indirect impacts are the long-term consequences of the former, including modifications of behaviour and habitat, and alterations of the biotic relationships between species (Wolf et al., 2019). In the present deliverable, we focus on non-consumptive activities (i.e. we exclude activities such as

⁵ Cox and Gaston, 2018 <https://doi.org/10.1098/rstb.2017.0092>

Diaz et al., 2018 <https://doi.org/10.1126/science.aap8826>

Rüdusser et al., 2019 <https://doi.org/10.1016/j.ecoser.2019.100980>

Subroy et al., 2019 <https://doi.org/10.1016/j.ecolecon.2019.106374>

⁶ Baker & Leberg, 2018 <https://doi.org/10.1371/journal.pone.0195436>

Geffroy et al., 2015 <https://doi.org/10.1016/j.tree.2015.09.010>

Monz et al., 2013 <https://doi.org/10.1890/120358>

hunting or fishing) and on impacts that can be broadly considered unintentional. It should be noted that, while impacts are generally concentrated on linear disturbance corridors (broadly corresponding to trails), some of them can extend way further into natural landscapes (Marion & Leung, 2001) and can have unpredictable cascading effects in environments that are already under pressure due to climate change (Asters-CEN74, 2025). The magnitude and final effect of these impacts thus vary greatly according to a wide range of factors (e.g. activity type, number of practitioners, species involved) (see for example Pescott & Stewart, 2014; Tablado & Jenni, 2017). However, two elements recur consistently across activities: disturbance to wildlife and trampling of vegetation. These impacts are therefore presented in general terms hereafter and recalled in the description of specific activities only to detail particular aspects.

1.2.1 Disturbance to wildlife

Human-caused disturbance of wildlife is defined as the deviation in the behaviour of an animal from the pattern observed in the absence of human influence (Frid & Dill, 2002). The predominant theoretical framework in this field is the predation risk-disturbance hypothesis (Frid & Dill, 2002), which argues that wildlife perceives and responds to human presence in the same way it perceives and responds to the risk of predation from other animals, with related energy trade-offs for fleeing, vigilance, reproduction, and foraging. Since animals tend to overestimate the risk deriving from humans even in the case of non-lethal activities (Frid & Dill, 2002), recreation can impact the fitness of individuals and the viability of populations, restructuring wildlife communities and representing a conservation issue (Storch, 2013; Suraci et al., 2019). Indeed, several studies confirm that recreational activities have generally negative impacts on wildlife (Hochreutener et al., 2022; Larson et al., 2016; Steven et al., 2011). While the most extreme response of wildlife to disturbance is death, which can also occur with non-consumptive activities (Miller, 1998) more commonly, the impacts manifest as “short-term changes in behaviour, long-term shifts in habitat use, reduced reproductive success and declining population” (Storch, 2013).

Tablado & Jenni (2017) propose a conceptual framework to structure these responses across four hierarchically related levels: (1) sensory detection of humans; (2) physiological and behavioural responses; (3) impacts on individual fitness, reproduction, and habitat use; and (4) consequences on demographic processes at the population level. At each level, the magnitude of the final effect depends on the interaction between the basic mechanisms of response (e.g. disturbed animals tend to flee) and a variety of factors that can amplify or reduce its intensity (e.g. the tendency to flee is increased by louder activities or reduced if the environment provides good shelter).

An important aspect concerns the predictability of disturbance, which can lower the stress experienced by animals. Over time, animals tend to adopt two main strategies to cope with recurrent human disturbance:

- Spatial avoidance involves changing movement patterns to avoid areas where human presence is more intense (Salvatori et al., 2023), such as trails, huts, or car parks.
- Temporal avoidance involves shifting activity patterns towards increased nocturnality to circumvent the stronger diurnal human presence (Gaynor et al., 2018); this can also be seen as a consequence of spatial avoidance, especially when available territory becomes insufficient.

Together, these strategies produce a "landscape of fear" (Laundré et al., 2010). While this avoidance can reduce the risk of direct encounters (Salvatori et al., 2023), it also displaces wildlife to suboptimal locations, reduces available territory, fragments population habitats, and decreases foraging opportunities, with cascading effects on populations and communities (Gaynor et al., 2018).

1.2.2 Damage to soil and vegetation

The impacts on soil and vegetation are deeply interrelated. As concerns soil, one of the main effects consists in soil compaction, which in turn determines decreased air and water permeability and altered terrain hydrology (Huddart, 2019; Kuwaczka et al., 2023). This can lead to excessive muddiness that may cause visitors to avoid wet spots, contributing to trail widening and creation of new trails and expanding disturbance to previously untouched areas (Marion & Leung, 2001). Another effect is represented by the removal of organic litter and erosion, directly through the passage of people and indirectly by the action of wind and water (Marion & Leung, 2001). These aspects are particularly accentuated when trails more directly ascend without following the natural contour and on steeper slopes (Leung & Marion, 1996). Alteration of pH and a loss of nutrients and microbial abundance are also recorded (Ballantyne & Pickering, 2015). All these aspects are especially relevant as they consequently impact vegetation. Soil compaction reduces the capacity for root penetration and seed germination (Huddart, 2019), lower nutrients and water absorption hinder root growth (Kuwaczka et al., 2023), while erosion exposes roots, affecting tree health (Marion & Leung, 2001).

Besides these indirect impacts, vegetation is affected by recreational activities both during the creation of trails (whether formal or informal) and during their use. The creation of trails requires removing plants on (and on the sides of) the track, potentially opening gaps in the canopy and allowing more light, heat and wind to reach the terrain (Pickering & Norman,

2017). When trails are used, impacts derive from trampling, i.e. by the direct mechanical disturbance deriving from the passage of people, which causes not only a lowering of plant height and a loss of vegetation cover, but also a loss of species richness (Asters-CEN74, 2025; Ballantyne & Pickering, 2015; Cole, 1987). Disturbance-sensitive species, including non-vascular plants like lichens, decline first, while stress-tolerant and ruderal species become dominant, leading to a decrease of native species and a shift in community structure (Ballantyne & Pickering, 2015; Jägerbrand & Alatalo, 2015; Pickering & Norman, 2017). Scientific literature points to the fact that, while the final effects increase with the intensity of disturbance (Cole, 1987), they largely depend on the intrinsic properties of vegetation (Pescott & Stewart, 2014). Yet, from a conservation standpoint, the most critical aspect is that trampling can cause severe damage even at low intensity, with the most substantial impacts occurring during the first trampling event (Cole, 1987; Kuwaczka et al., 2023; Pescott & Stewart, 2014). This is particularly relevant in the case of alpine vegetation, which is generally slow to recover (Ballantyne & Pickering, 2015; Jägerbrand & Alatalo, 2015).

Finally, recreational activities can alter plant composition also by introducing alien species and pathogens, especially in the vicinity of trails (Chisholm & McCune, 2024). These phenomena underline the importance of avoiding the creation of new, informal trails, especially in the presence of rare or endangered species, and of concentrating as much as possible human frequentation in terms of spatial reach. At the same time, disturbance associated with trails may create opportunities for colonization by weaker competitors or disturbance-adapted species and may determine a local increase in species richness (Wedegärtner et al., 2022). This may also result in shifts in the distribution of alpine species along trails, including expansions towards lower elevations. However, these findings do not offset the broader ecological risks associated with trampling and the potential loss of rare or disturbance-sensitive species, but rather highlight the importance of site-specific assessments prior to trail management decisions.

1.3 Impacts of specific nature-based activities on biodiversity

1.3.1 Hiking

As part of the LiveAlpsNature project, in the summer season of 2025 a survey was conducted to collect information about the visitors of Alpine protected areas (their preferred activities, sources of information, perception of tourism impacts on biodiversity, etc.). The results show that hiking is by far the main reason for visiting nature in all participating protected areas, with

figures ranging from 69% to 82%, and approximately 95% of respondents include it among their top five preferred activities⁷. Although it is commonly considered a low-impact activity, scientific literature points to the fact that all nature-based activities, hiking included, have an effect on biodiversity and that this effect is generally negative (Gaynor et al., 2018; Larson et al., 2016; Steven et al., 2011). While even individual impacts can cause conservation issues when damaging rare or endangered species, it is the volume of visitors engaging in hiking that represents the main problem for its potential cumulative consequences. It should also be noticed that hiking constitutes an integral part of many other outdoor activities, aimed at reaching dedicated sites in areas that are generally vehicle-free, for example, approaching climbing cliffs.

The main impacts of hiking on biodiversity can be summarised as follows:

- Direct disturbance to fauna, that can be amplified if wildlife observation is the goal of the hike or in case of dog walking, and potentially direct damage to smaller animals
- Indirect damage to fauna caused by habitat fragmentation, deriving from avoidance of the most frequented areas (such as trails and their surroundings)
- Direct damage to flora caused by trampling
- Soil compaction and erosion
- Creation of informal trails
- Introduction of alien plant species and dispersal of pathogens

The disturbance caused by hikers on both vegetation and wildlife broadly corresponds to the baseline described in Section 1.2. However, as mentioned above, various factors can contribute to substantially amplifying these impacts. Some examples are presented below.

According to the review by Tablado & Jenni (2017), animals are more likely to detect humans if they move in large groups and generate considerable noise. While this can give animals enough time to react, the same factors are also associated with a greater perception of risk, meaning that large and loud groups trigger higher stress and stronger behavioural responses. This is also confirmed by an experiment led by Zeller et al. (2024), who found that noise from vocal, large groups of hikers determines the highest probability of individual flight compared to other activities (such as biking, trail running). At the same time, vigilance time tends to

⁷ The results of the survey are presented in Deliverable D.1.1.1 and its Annexes. While the sample cannot be considered statistically representative of the total population of visitors and the findings are therefore not strictly generalizable, the magnitude of the expressed preferences for hiking (as well as closely related activities such as nature contemplation and relaxation) is sufficiently pronounced to allow robust interpretative conclusions and is also supported by the direct experience of protected area managers.

increase with noise caused by smaller groups. In any case, the probability of fleeing and the proportion of vigilance time are both lower for smaller, silent groups, proving how hikers' behaviour has an effect on disturbance.

Overall, the interaction between human behaviour and wildlife response follows the general rule according to which "Animals are more distressed by recreationists appearing suddenly in an unpredictable way" (Tablado & Jenni, 2017). Off-trail hiking has been shown to produce stronger and more disruptive responses compared to on-trail hiking. Westekemper et al. (2018) found that red deer (*Cervus elaphus*) in a German forest fled significantly earlier and over greater distances when disturbed by hikers off-trail, while they didn't seem to react to hiking on designated paths, keeping a distance large enough to avoid flight responses during activity peaks (i.e. daytime). Taylor & Knight (2003) reported similar findings for mule deer (*Odocoileus hemionus*), with off-trail hikers triggering earlier alertness and longer distances covered during flight than on-trail hikers. This should be particularly considered when wildlife observation is the primary goal of the excursion, potentially leading people to approach animals more closely in their habitat or directly interfering with them (Sekercioglu, 2002; Tablado & Jenni, 2017). The temporal equivalent of off-trail hiking can be considered walking during nighttime or other moments when animals are particularly active and less used to human presence, such as dawn or dusk (Gaynor et al., 2018; Salvatori et al., 2023).

Dog walking represents a well-documented amplifier of hiking disturbance. Wildlife perceives dogs as potential predators, independently of them being on a leash or not, triggering predator-avoidance responses that add to those caused by the human presence alone (Hennings, 2016). For example, Miller (1998) found that mule deer fled over substantially greater distances when hikers were accompanied by a dog, both on-trail and off-trail, while Parsons et al. (2016) showed that different mammal species (namely, white-tailed deer, eastern gray squirrel and raccoons) exhibited the most pronounced temporal avoidance of recreational areas when humans were present together with dogs. The effect of dogs is also relevant for birds, as reported by a review finding negative impacts in all the 11 articles taking into account dog walking (Steven et al., 2011). For example, Banks & Bryant (2007) observed that dog walking in Australian woodlands caused a 41% reduction in bird abundance and a 35% reduction in bird species richness, with particular impacts on ground-dwelling birds. Besides disturbance, dogs can also spread diseases and directly prey on wildlife species (Hennings, 2016). Notably, the negative effects of dog walking extend beyond terrestrial environments. Studying recreational impacts on small lakes, Schafft et al. (2024) found that dogs, whether leashed or not, have greater biodiversity impacts than the sole presence of

humans and were consistently associated with a decrease in species richness of songbirds, fish and riparian herbs.

While most amplifying factors concern hiking impacts on fauna, an important remark should be made for flora as well. Indeed, several studies report that vegetation is impacted by human trampling also at low levels of activity intensity and that damage is stronger at the beginning of the trampling phenomenon (Cole, 1987; Jägerbrand & Alatalo, 2015; Kuwaczka et al., 2023), stressing the importance of keeping visitors on-trail also for flora conservation.

Various management measures can be derived from these studies, in particular:

- Concentration of visitors in some areas to leave wider undisturbed habitats
- Strict trail obligations to reduce off-trail disturbance, particularly in core habitat zones, and closure of informal trails
- Temporal access restrictions in high-sensitivity habitats and periods, and limitations on nighttime access
- Obligation to keep dogs on a leash and total ban on dogs in sensitive areas and during specific periods (e.g. breeding and rearing).

Impact	Management measure
General recommendation	<ul style="list-style-type: none"> ▪ Intensification of visitor and wildlife monitoring ▪ Coordination of visitor and wildlife monitoring between protected areas ▪ Awareness-raising activities on the impacts and good practices concerning hiking
Stronger impacts caused by unpredictable disturbance	<ul style="list-style-type: none"> ▪ Limitation and strategic positioning of access points to protected areas to better direct visitor flows
Stronger impacts caused by off-path hikers	<ul style="list-style-type: none"> ▪ Obligation to stay on paths ▪ Physical delimitation of paths (e.g. with plant barriers or visual delimitation)
Stronger impacts caused by hikers with dogs	<ul style="list-style-type: none"> ▪ Total ban on dogs in protected areas ▪ Obligation to keep dogs on a leash
Spatial avoidance and decrease of available habitat (habitat fragmentation)	<ul style="list-style-type: none"> ▪ Concentration of hikers in specific areas ▪ Reduction of the number of paths ▪ Suppression of ephemeral/social paths and restoration ▪ Intensification of the use of existing paths

Impact	Management measure
Temporal avoidance and shift to nighttime activity	<ul style="list-style-type: none"> ▪ Temporal restriction of access to paths ▪ Prohibition of hiking during nighttime (e.g. from sunset to sunrise)
Stronger impacts during breeding and rearing season	<ul style="list-style-type: none"> ▪ Temporal restriction of access to paths ▪ Closure of (specific) hiking paths during breeding and rearing season
Stronger impacts during wintertime (see Par 1.3.5)	<ul style="list-style-type: none"> ▪ Temporal restriction of access to paths ▪ Closure of (specific) hiking paths during winter
Stronger impacts in open spaces (compared to areas providing shelter)	<ul style="list-style-type: none"> ▪ Temporal restriction of access to paths ▪ Closure of paths crossing open spaces

Table 1.1 Main impacts and management measures for hiking

1.3.2 Mountain biking

Mountain biking (MTB) represents a rapidly growing outdoor sport in the Alps, a trend especially accelerated by the spread of electrically assisted mountain bikes (e-MTB) but also by the conversion of winter sports infrastructure into year-round recreational spots (Moesch et al., 2022). Besides the risk of increasing conflict between different types of visitors, particularly with hikers (Pröbstl-Haider et al., 2018), this trend is particularly relevant for Alpine protected areas as it poses two key challenges for conservation (Mitterwallner et al., 2021). On the one hand, compared to traditional mountain bikes, e-MTBs enable users to reach more remote and high-altitude areas, that were previously mostly inaccessible to two-wheeled vehicles; on the other hand, they lower physical barriers to access, expanding the number of practitioners and, as a consequence, the aggregated number of passages (in- and off-trail). All the impacts listed hereafter, are thus expected to be substantially amplified by e-MTBs (Kuwaczka et al., 2023).

The main impacts of MTB and e-MTB on biodiversity can be summarised as follows:

- Direct disturbance to fauna and potentially direct damage to smaller animals, which can be amplified by the higher speed and greater distance covered per unit of time (compared to hiking)
- Indirect damage to fauna caused by habitat fragmentation, deriving from avoidance of the most frequented areas (such as trails and their surroundings)
- Direct damage to flora caused by trampling
- Soil compaction and erosion, particularly on steep or wet terrain

- Creation of informal trails, especially in previously undisturbed areas
- Introduction of alien plant species and dispersal of pathogens over longer distances

Some examples are presented below concerning impacts on both fauna and vegetation.

Overall, the type of disturbance caused by cyclists on wildlife resembles that of hikers, although some crucial differences exist. Comparative studies found that mountain biking causes animal flight (Kuwaczka et al., 2023) and avoidance (Coppes et al., 2017) responses to a similar or higher degree than hiking, although reactions seem to be highly species-specific (Mitterwallner et al., 2021). In any case, the fact that cyclists cover longer distances is likely to increase the number of individuals disturbed per unit of time (Taylor & Knight, 2003) and the spatial extent of disturbance, while their generally more silent approach could reduce the ability of animals to detect them at greater distances (Tablado & Jenni, 2017), potentially increasing abrupt and energy-consuming responses. As concerns ungulates, a study on North American elks (a species similar to red deer) by Naylor et al. (2009), reported that mountain biking has stronger effects compared to hiking in terms of reduction in feeding time and increase in travel time. Scholten et al. (2018) observed that red deer spatially avoid biking trails and that, although this behaviour increases with human activity during daytime, it is well detectable already at a low intensity of the activity. Wyttenbach et al. (2016) showed that roe deer flee longer distances when disturbed by mountain biking at night than at dawn (a time when they are particularly active), but also that the disturbance was greater for off-trail activities compared to on-trail mountain biking.

The direct mechanical effects of mountain biking are broadly comparable to those of hiking also regarding vegetation and soil, but this very much depends on the environmental conditions. On flat and dry terrains, impacts in terms of “increased water runoff, sediment yield and/or soil exposure, together with vegetation and/or species loss” (Hardiman & Burgin, 2013), do not differ much between the two activities. However, changes in trail depth (Evju et al., 2021), soil compaction and trampling due to high use (Kuwaczka et al., 2023) appear to be stronger for MTB than for hiking. Under wet conditions or in moist terrains, mountain biking clearly demonstrates higher trail degradation (Evju et al., 2021). In general, the strongest impacts occur at the first passes of MTBs, on downhill and uphill slopes and curves, due to braking, skidding and spinning (Hardiman & Burgin, 2013). Similarly to what was presented for fauna, the longer distances covered by cyclists per unit of time expand the spatial disturbance and can contribute to dispersing invasive species seeds or plant pathogens further compared to hikers (Kuwaczka et al., 2023).

The examples presented confirm that well-defined (and respected) trail networks reduce mountain biking impacts on both wildlife and vegetation, while the creation of new, ephemeral trails risks determining habitat fragmentation and more severe damage to sensitive species.

Various management measures can be derived from these studies, in particular:

- Restriction of MTB and e-MTB access to designated trails, with particular attention to high-altitude and remote areas
- Total ban on MTB and e-MTB during specific periods (e.g. breeding and rearing), at least in the most sensitive habitats
- Limitation of new MTB trails, physical closure of ephemeral trails and use of barriers in spots particularly subject to ephemeral trail creation
- Design of MTB trails in generally dry areas with moderate slopes
- Altitude limit for e-MTB access, to preserve high-altitude refuges from disturbance
- Installation of bike racks in spots where cyclists are required to proceed by foot (e.g. trailhead of hiker-only itineraries)

Impact	Management measure
General recommendation	<ul style="list-style-type: none"> ▪ Assessment of wildlife sensitivity and vegetation value along existing and proposed MTB trails ▪ Awareness-raising initiatives targeted at MTB and e-MTB users ▪ Installation of bike racks where cyclists are required to proceed by foot
Direct disturbance to fauna (vigilance, flight, stress)	<ul style="list-style-type: none"> ▪ Restriction of MTB/e-MTB to designated trails ▪ Total ban of MTB and e-MTB during specific periods (e.g. breeding and rearing)
Spatial and temporal avoidance causing habitat fragmentation	<ul style="list-style-type: none"> ▪ Reduction and rationalisation of the trail network ▪ Creation of trail-free core zones as undisturbed refuges ▪ Physical closure of ephemeral trails and barriers in spots particularly subject to ephemeral trail creation
Disturbance to high-altitude fauna (e-MTB)	<ul style="list-style-type: none"> ▪ Altitude ceilings for e-MTB access ▪ Total restriction from designated wilderness/remote refuges
Soil erosion and compaction (steep/wet terrain)	<ul style="list-style-type: none"> ▪ Trail routing criteria excluding wet terrain and steep gradients ▪ Seasonal closure of vulnerable trail sections

Impact	Management measure
Vegetation damage and informal trail creation	<ul style="list-style-type: none"> ▪ Strict enforcement of designated trail use ▪ Physical closure of ephemeral trails and barriers in spots particularly subject to ephemeral trail creation
Introduction of alien species and pathogens	<ul style="list-style-type: none"> ▪ Tire cleaning stations at trailheads ▪ Restriction from sensitive high-altitude habitats

Table 1.2 Main impacts and management measures for mountain biking

1.3.3 Trail running

Trail running is emerging as an increasingly popular activity, as shown by the huge growth in the number of events and competitions taking place in Europe. For example, in France the number of events has grown from 150 in 2001 to 2500 in 2015 and 4968 in 2024, with over 20% of them taking place in the Alpine region of Auvergne-Rhône-Alpes (Asters-CEN74, 2025; PRNSN CREPS, 2025).

The main impacts of trail running on biodiversity can be summarised as follows:

- Direct disturbance to fauna and potentially direct damage to smaller animals
- Indirect damage to fauna caused by habitat fragmentation, deriving from avoidance of the most frequented areas (such as trails and their surroundings)
- Direct damage to flora caused by trampling
- Soil compaction and erosion
- Creation of informal trails
- Introduction of alien plant species and dispersal of pathogens

While trail running shares the same types of impacts as hiking, research suggests that these are amplified by some specific factors such as: (a) the higher speed of runners, (b) the temporal shifts of events towards nighttime, and (c) the scale of the events in terms of the number of participants. Some examples are presented below, with a focus on amplifying factors and taking as the main reference the *Opinion of the Scientific Committee of the Haute-Savoie National Nature Reserves on the organisation of trail running events in nature reserves* (Asters-CEN74, 2025).

As concerns speed, the faster pace of trail runners compared to hikers can reduce the warning time available to animals, amplifying flight distances and stress responses, in accordance with the predator risk-disturbance hypothesis, under which unpredictable, fast-moving stimuli are

perceived as a greater threat than slow, predictable ones (Tablado & Jenni, 2017; Wisdom et al., 2018). Moreover, while vocal groups of hikers can increase the probability of flight compared to small groups of runners, the vigilance time caused by the latter is higher, and both values are higher compared to small, quiet groups of hikers (Zeller et al., 2024). As is the case for mountain biking, the potentially longer distances covered by trail runners can increase the number of animals disturbed per unit of time.

Since wildlife has adapted to avoid human disturbance by shifting its activities to nocturnal hours (Gaynor et al., 2018; Salvatori et al., 2023), nighttime trail running introduces a further dimension of impact. As a reference, Asters-CEN74 (2025) estimates that 90% of human nighttime presence on trails in monitored French Alpine reserves is attributable to trail runners compared to only 2%-5% during daytime, while the website Run the Alps expects for 2026 more than 30 ultratrail races of more than 100km, usually taking place over several days⁸. That means that, besides suffering from reduced efficiency in their physiological activity during the night, animals risk suffering from unexpected disturbance and losing their temporal refugia (Asters-CEN74, 2025), with an increasing impact on habitat fragmentation.

Finally, competitive mass events represent a qualitatively distinct impact from individual trail running. As already mentioned, the number of trail running races has grown exponentially over recent decades (see also Babí et al., 2019)), concentrating hundreds or thousands of participants on narrow and ecologically sensitive paths within very short time windows. Marchand et al. (2025), studying Alpine ibex (*Capra ibex*) in a French protected area, found that trail running events exacerbated the “corridors of fear”, with increased redistribution farther from paths (compared to usual human presence) and higher activity and movement when closer to this infrastructure. They also suggest that these negative effects could be amplified in cases where mass competitions overlap with crucial moments such as the birth period, with potential consequences on reproductive outputs. A study on a running competition in a Hong Kong protected area (Ng et al., 2018) showed that the intensity of impacts caused by runners was much higher than that of hikers on several indicators for soil, such as tread width and incision, compaction, litter removal and tree root exposure, with some of them persisting even 7 months after the event. As with mountain biking, these impacts are increased by wet conditions (Asters-CEN74, 2025).

⁸ Run the Alps – Race Finder: <https://www.runthealps.com/races>

Various recommendations for management measures are directly proposed or can be derived from these studies, in particular:

- Limitation of the number of trail running events and of participants per event
- Total ban on trail running events during particularly sensitive periods (e.g. breeding and rearing) and during nighttime
- Co-design between protected area managers and organisers of competition itineraries to avoid sensitive areas, possibly finding alternatives outside protected area borders

Impact	Management measure
General recommendation	<ul style="list-style-type: none"> ▪ Ecological assessment prior to race authorisation in protected areas ▪ Awareness-raising targeting runners, particularly regarding off-trail behaviour and nighttime impacts
Amplified disturbance from speed of movement	<ul style="list-style-type: none"> ▪ Trail obligation with strict enforcement ▪ Buffer zones around sensitive habitats along race routes
Mass event disturbance and habitat displacement	<ul style="list-style-type: none"> ▪ Authorisation system for competitive events in protected areas ▪ Restrictions on event timing (breeding/rearing season, April–July) and location ▪ Participant caps
Concentrated soil and vegetation damage from mass events	<ul style="list-style-type: none"> ▪ Post-event monitoring and mandatory trail restoration by organisers ▪ Rotation of race routes to allow recovery
Nighttime disturbance eliminating temporal refuge	<ul style="list-style-type: none"> ▪ Prohibition or restriction of nighttime racing and training in sensitive zones
Introduction of alien species via footwear	<ul style="list-style-type: none"> ▪ Shoe cleaning stations at trailheads ▪ Prohibition of off-trail shortcuts

Table 1.3 Main impacts and management measures for trail running

1.3.4 Rock climbing

Cliffs represent unique and generally untouched habitats, supporting highly specialised, endemic and/or endangered species (Morales-Armijo et al., 2024; Schmera et al., 2018). Given the high conservation value of cliff biodiversity, studies addressing the impacts of climbing generally begin by acknowledging the rapidly increasing popularity of this activity and the need

to define adapted management measures. Cliff ecosystems are affected by climbing in different ways:

- Disturbance of cliff-nesting birds and potentially direct damage to smaller animals
- Direct damage to cliff vegetation due to abrasion, intentional plant removal for route opening and removal of soil from crevices
- Indirect damage to cliff vegetation caused by chalk and climbing shoes microplastics, and to cliff fauna because of ecosystem alteration
- Trampling of cliff-base vegetation during approach and securing
- Introduction of alien species, such as alien plants

Some examples are presented below concerning impacts on both flora and fauna. The most evident impact on fauna regards the disturbance of birds nesting on cliffs. Brambilla et al. (2004) observed that the presence of climbers has a negative effect on the breeding success of the Peregrine Falcon (*Falco peregrinus*), affecting the number of successful pairs. This effect is even stronger if other conditions occur simultaneously, in this case, the presence of ravens at the nesting cliffs. Research conducted in the Colorado mountains by Covy et al. (2019) indicates that “rock climbing has negative impacts on cliff bird community diversity and conservation value, and mixed effects on individuals”, also indicating that certain species could have a relative tolerance towards human activity. Besides, cliff aspect (i.e. the natural physical characteristic of the site) emerges as one of the best predictors of avian diversity and cliff use, and east-facing cliffs appear to have the highest avian diversity. The fact that the results of these studies can highly depend on the features of the environment and species considered, suggests that conservation measures should be grounded in site- and species-specific assessments, tailored to the local ecological context.

Impacts are also reported by Schmera et al. (2018) on invertebrates such as snails. The study focused on limestone cliffs in the northern Swiss Jura and showed a negative effect on both species richness and abundance of land snails, which are crushed by climbers, with stronger impacts on species with larger shell sizes. Similar impacts occur for vegetation. As regards cliff faces, they observed a reduction in plant species richness, which appeared to be more pronounced for species with high rock specificity (becoming locally extinct on climbing routes) and also affected stress-tolerant species, and observed that recolonization was prevented by repeated removal of plants and soil from crevices. As concerns the other sections of the cliffs, both vegetation cover and the litter layer were decreased at the cliff base due to trampling and the intentional introduction of trampling-tolerant species was also recorded, while top plateaus (generally not accessed by climbers) appear to be unaffected. While for both snails

and plants the impact increases with climbing intensity, the negative effects on biodiversity were recorded even at low climbing intensity.

Focusing on vascular plants in a mountain protected area of Mexico, March-Salas et al. (2023) warn that climbing causes the loss of rare and endemic species, but also that dominant species suffer the greater loss of individuals. Both these phenomena are worrying since they have an impact on the positive association between species and can compromise cliff plant community functioning. The study also suggests that negative impacts derive primarily from the first ascents, rather than depending on the level of climbing use intensity. This insight is confirmed by subsequent works by Morales-Armijo et al. (2024) (Mexico – vascular plants and lichens) and Österle et al. (2026) (Germany – lichens and bryophytes). Both studies confirm that the opening of new routes and the first ascents cause the strongest damage to cliff vegetation, attributable to operations such as “removing plants, mosses, and lichens along the planned route transect to ensure safe climbing” (Morales-Armijo et al., 2024). However, Österle et al. (2026) also observed that, when prior vegetation removal was not actively implemented, the impact on cliff vegetation was considerably lower, and that the percentage of vegetation loss is influenced by rock properties (e.g. erosion rate).

Finally, less visible impacts could derive from climbing equipment. Hepenstrick et al. (2020) indicate that “climbing chalk might negatively affect mosses and ferns growing along climbing routes” (even if the influence could vary depending on the rock type and other environmental factors), and Österle et al. (2026) detected microplastics and rubber additives from climbing shoe sole abrasion, that can be particularly problematic as they are “released directly into sensitive ecosystems”.

Various recommendations for management measures are directly proposed or can be derived from these studies, in particular:

- Limitation of climbing at cliffs hosting endangered raptors, with a total ban during the breeding season or when the presence of other competing birds is recorded
- Total ban of climbing on cliffs (or cliff sectors) that present a high number of specialized, rare, endemic and/or endangered species
- Limitation of new route opening, and in any case prior assessment of biodiversity in the interested cliff (or cliff sector)

Impact	Management measure
General recommendation	<ul style="list-style-type: none"> ▪ Assessment of presence of specialized/rare/endemic/endangered species at cliffs (potential climbing sites) ▪ Awareness-raising initiatives targeted at climbers
Disturbance to nesting birds affecting breeding success	<ul style="list-style-type: none"> ▪ Limitation of climbing at cliffs hosting rare/endemic/endangered birds ▪ Total ban of climbing during the breeding season or when the presence of other competing birds is recorded
Direct damage to small animals (e.g. invertebrates)	<ul style="list-style-type: none"> ▪ Total ban of climbing on cliffs/cliff sectors with high biodiversity conservation value
Direct damage to cliff vegetation (also at cliff bases)	<ul style="list-style-type: none"> ▪ Total ban of climbing on cliffs/cliff sectors with high biodiversity conservation value ▪ Possible rotation of cliff opening to allow for vegetation recovery
Damage from opening new routes (strongest)	<ul style="list-style-type: none"> ▪ Assessment of presence of specialized/rare/endemic/endangered species ▪ Total ban on sensitive sites and concentration of routes in a few sites (not merely a reduction of climbing intensity) ▪ Training for people in charge of opening and maintaining climbing routes ▪ Limitation of vegetation removal when opening a route
Indirect damage to cliff vegetation due to climbing equipment	<ul style="list-style-type: none"> ▪ Limitation of use of climbing chalk ▪ Total ban on sensitive sites and concentration of routes in less sensitive sites (not merely a reduction of climbing intensity)
Introduction of alien species	<ul style="list-style-type: none"> ▪ Total ban on sensitive sites and concentration of routes in a few sites ▪ (Shoe cleaning spot at the beginning of the approach path)

Table 1.4 Main impacts and management measures for rock climbing

1.3.5 Winter sports

Winter recreation in the Alps can be grouped into two main categories: activities taking place in ski resorts, which concentrate users in defined areas but involve permanent and seasonal habitat modifications due to infrastructural needs (Sato et al., 2013); and backcountry activities (e.g. ski touring and snowshoeing), which do not require permanent infrastructure but which spatial extent is less predictable and potentially overlaps winter refuges for the most sensitive species (Walter et al., 2024). These activities occupy a specific position in the assessment of biodiversity impacts, because they operate precisely when the Alpine environment places the greatest stress especially on fauna. Animal species that remain active in winter (Cremer-Schulte et al., 2017), like tetraonid birds (capercaillie, *Tetrao urogallus*; black

grouse, *Lyrurus tetrix*; rock ptarmigan, *Lagopus muta*), chamois (*Rupicapra rupicapra*), and mountain hare (*Lepus timidus*), face harsher conditions of scarce food availability, reduced shelter offered by vegetation, impeded movement in snow and higher thermoregulation costs (Peters et al., 2023). In these conditions, animals typically adopt strategies allowing to minimize energy expenditure, since any additional effort such as those caused by disturbance (e.g. vigilance, flight, behavioural adaptation) directly erodes reserves that are already critically limited (Neumann et al., 2009). This interaction between physiological vulnerability and recreational pressure makes winter activities a qualitatively distinct concern from summer recreation, with greater evidence of negative effects on wildlife (Larson et al., 2016).

The main impacts of winter recreational activities on Alpine biodiversity include:

- Direct disturbance to fauna, with more severe consequences compared to summer disturbance events due to harsher conditions, and potentially direct damage to smaller animals
- Indirect damage to fauna caused by habitat fragmentation, deriving from avoidance of the most frequented areas (e.g. ski resorts and common backcountry routes)
- Direct mortality, for example from collision with ski infrastructure
- Direct damage to flora and soil, from activities associated with ski piste preparation
- Disruption of subniveal microhabitat
- Interaction with climate change, as snow-covered areas shift upwards creating increased overlaps between skiable terrain and climate refugia for biodiversity

Some examples are presented below concerning impacts on both fauna and vegetation.

Several studies focused on Galliformes, considered to be a good indicator of the state of timberline ecosystems (Walter et al., 2024) but also as the most susceptible to disturbance from activities like ski mountaineering (Jäger et al., 2020). Measuring corticosterone metabolite concentrations in faecal samples from disturbed black grouse, Arlettaz et al. (2007) showed that activities such as freeride skiing and snowboarding represent a stress factor, that could result in chronic stress if repeated over successive days. Besides the potential long-lasting effects, every time black grouse flee from their under-snow igloos, they need to thermoregulate more intensively and are more exposed to predation. In a subsequent study, Patthey et al. (2008) extended the analysis to the population level, testing the effect of ski lifts and related winter activities on black grouse abundance. By comparing males displaying during the breeding season at 15 ski resorts and 15 natural undisturbed sites, they estimated abundance to be approximately 36% lower close to ski facilities, with impacts extending up to 1500m from ski lifts. Most recently, Romportl & Erlebach (2025) documented the situation of

black grouse in the Krkonoše Mountains in terms of a sharp reduction, degradation and fragmentation in core habitat areas, very low probability of dispersal of individuals and/or subpopulations, a gradual disappearance of individual subpopulations and the risk of extinction of the entire population. Notably, recreational intensity was indicated as the most important factor for this tendency.

As concerns capercaillie, Thiel et al. (2008) combined radio tracking and analysis of corticosterone metabolites in droppings, showing that ski tourism simultaneously triggers habitat use changes and physiological responses. While capercaillie showed a preference for undisturbed forest patches and only approached ski areas in periods of low human presence, this change occurred within individuals' home ranges. At the same time, stress-related responses appeared to be more pronounced than behavioural responses, suggesting that capercaillie may be forced to live human-disturbed, suboptimal habitats, with potential downstream consequences for fitness. Coppes et al. (2017) confirmed this aspect, and also quantified the effective habitat loss for capercaillie in the Black Forest using radiotelemetry data, estimating that up to 40% of its winter distribution was potentially disturbed by recreational activities, that avoidance distances are greater in winter than in summer and that they are greater than flushing distance (suggesting impacts of human disturbance far beyond the triggering response distance).

Jäger et al. (2020), overlaying crowdsourced GPS ski touring data (Strava platform) with grouse species distribution maps in the Tyrol region, found that ski mountaineering affected 10.3% of the black grouse potential distribution area and 8.6% of the capercaillie area. Critically, backcountry activity began at dusk and showed a secondary peak after sunset, which represents exactly the short time windows during which these species must feed to survive winter.

Some works also focus on mammals. For example, Rehnus et al. (2014) measured faecal glucocorticoid metabolites in mountain hares living in areas with zero, medium, and high winter tourism intensity. As with the above-mentioned studies, they found a positive correlation between tourism intensity and stress hormone excretion, meaning that additional energy expenditure might occur precisely when food is least available. Outside the European Alps, Neumann et al. (2009) observed that off-trail backcountry skiing triggered a distinct, short-term increase of movement rate, with an energy expenditure almost doubled. The authors underline that while this could have minor impacts for healthy adults, it might negatively affect the physical condition and survival of calves, suggesting that negative population effects could emerge for smaller animals for which moving in snowy winter conditions is more costly.

The comparative reviews by Sato et al. (2013) and Larson et al. (2016) place these findings in a global context: snow-based recreational activities show a higher frequency of documented negative effects on wildlife than any other recreational category. Looking forward, Roseo et al. (2025) show that 11% of Alpine climate refugia currently overlap with current ski slopes, with one third of pistes already associated with possible impacts on climate change-sensitive species. As average temperatures rise, ski pistes distribution is also expected to shift upwards. Under climate change projections the overlap between climate refugia and areas suitable for pistes may reach 69–72%, placing ski resort development on a collision course with the areas most critical for future biodiversity conservation.

Regarding vegetation and soil, Rolando et al. (2007) suggest that the lower bird density and reduced arthropod richness and abundance on high-altitude ski pistes compared to adjacent natural grasslands derive from a cascade effect: the soil degradation and mechanical damage of local vegetation caused by ski piste preparation determine invertebrate depletion and thus a loss of feeding habitat for grassland bird communities. Casagrande Bacchiocchi et al. (2019) showed that medium-sized ski resorts (four to five months of operation) caused measurable reductions in plant biomass and species richness on slopes, while this was not the case for small resorts (two to three months). The authors conclude that these effects may be driven by duration and chemical properties of (artificial) snow cover as well as by direct mechanical damage, and report that they are even stronger in bigger resorts.

Various recommendations for management measures are directly proposed or can be derived from these studies, in particular:

- Establishment of wildlife refuge zones in areas suitable for sensitive species, with no-access rules for backcountry winter recreation
- Temporal restrictions on snow-based activities at dawn and dusk in sensitive areas
- Halting further upward expansion of ski resort infrastructure, particularly into areas identified as climate refugia, and minimally invasive piste construction
- Restriction of artificial snowmaking, both to reduce direct vegetation and soil modification and to avoid extending the ski season
- Mitigation of ski infrastructure collision risk, including installation of bird diverters on lift cables

Impact	Management measure
General recommendation	<ul style="list-style-type: none"> ▪ Intensification of visitor and wildlife monitoring and coordination between protected areas ▪ Assessment of presence of specialized/rare/endemic/endangered species near ski resorts or potential backcountry sites ▪ Awareness-raising activities on the impacts and good practices regarding winter sports
Stronger impacts caused by unpredictable disturbance / unpredictability of cross-country itineraries	<ul style="list-style-type: none"> ▪ Limitation and strategic positioning of access points to protected areas to better direct visitor flows. ▪ Obligation to stay on delimited pistes ▪ Physical delimitation of pistes (e.g. with plant barriers or visual delimitation) ▪ Establishment of wildlife refuge zones in areas suitable for sensitive species, with no-access rules for backcountry winter recreation;
Direct mortality, for example from collision with ski infrastructure	<ul style="list-style-type: none"> ▪ Mitigation of ski infrastructure collision risk, including installation of bird diverters on lift cables. ▪ Halting further upward expansion of ski resort infrastructure, particularly into areas identified as climate refugia, and minimally invasive piste construction
Direct damage to flora and soil, from activities associated with ski piste preparation	<ul style="list-style-type: none"> ▪ Restriction of artificial snowmaking, both to reduce direct vegetation and soil modification and to avoid extending the ski season ▪ Halting further upward expansion of ski resort infrastructure, particularly into areas identified as climate refugia, and minimally invasive piste construction
Spatial avoidance and decrease of available habitat (habitat fragmentation)	<ul style="list-style-type: none"> ▪ Obligation to stay on delimited pistes : concentration of practitioners in specific areas ▪ Reduction of the number of pistes ▪ Establishment of wildlife refuge zones in areas suitable for sensitive species, with no-access rules for backcountry winter recreation; ▪ Halting further upward expansion of ski resort infrastructure, particularly into areas identified as climate refugia, and minimally invasive piste construction
Temporal avoidance and shift to nighttime activity	<ul style="list-style-type: none"> ▪ Temporal restrictions on snow-based activities at dawn and dusk in sensitive areas ▪ Total ban on night opening of ski resorts
Stronger impacts during breeding and rearing season	<ul style="list-style-type: none"> ▪ Temporal restriction of access to pistes / certain areas during critical periods.

Impact	Management measure
Stronger impacts in open spaces (compared to areas providing shelter, such as forests)	<ul style="list-style-type: none"> ▪ Closure of (specific) areas during winter
Stronger impacts due to climate change (snow-covered areas shift upwards creating increased overlaps between skiable terrain and climate refugia for biodiversity)	<ul style="list-style-type: none"> ▪ Establishment of wildlife refuge zones in areas suitable for sensitive species, with no-access rules for backcountry winter recreation; ▪ Halting further upward expansion of ski resort infrastructure, particularly into areas identified as climate refugia, and minimally invasive piste construction

Table 1.5 Main impacts and management measures for winter sports

1.4 Discussion

The present bibliographic analysis shows the manifold ways in which non-consumptive nature-based activities disturb wildlife and damage vegetation and soil. Such negative impacts hold across activity types, seasons, habitats, and taxonomic groups, as also reported by existing global syntheses (Hochreutener et al., 2022; Larson et al., 2016; Sato et al., 2013; Steven et al., 2011). The situation becomes particularly critical when recreational activities occur within Alpine Protected Areas, among the most ecologically sensitive environments in the world. In the context of mounting pressure from climate change, the tension between conservation objectives and the growing demand for recreational and economic activities in these areas is becoming increasingly acute.

As concerns fauna, the central theoretical framework consists in the predation risk-disturbance hypothesis (Frid & Dill, 2002): wildlife perceives human presence as a predation threat and responds with anti-predator behaviour. However, while these strategies evolved in response to natural predators, animals have not developed specific adaptations to cope with anthropogenic disturbance, especially when it is more irregular and pervasive (Tablado & Jenni, 2017). As a result, wildlife may systematically overestimate risk from non-lethal activities and invest excessive energy in avoidance and flight responses, with negative effects documented even at low levels of recreational intensity (Scholten et al., 2018; Zeller et al., 2024). Animals attempt to respond to disturbance by changing their habits: spatially, they displace further from intensely used trail infrastructure (Coppes et al., 2017; Marchand et al.,

2025); temporally, species that are mainly diurnal shift their activities to nighttime, taking advantage of periods when humans are absent or less present (Gaynor et al., 2018). Although these adaptations can reduce the probability of direct disturbance (Salvatori et al., 2023), they carry major ecological costs: spatial displacement reduces available habitat and can lead to confinement in suboptimal areas (Tablado & Jenni, 2017), while nocturnal activity exposes species to reduced foraging and orientation, greater predation risk, and generally lower physiological efficiency (Gaynor et al., 2018; Salvatori et al., 2023).

A key issue that remains insufficiently clarified in the literature concerns the distinction between immediate and long-term effects of disturbance. In the short term, disturbance primarily affects individuals: responses have been documented at both the behavioural (feeding interruption, increased vigilance, flight initiation) and physiological (elevated corticosterone metabolites) level, consistently indicating recreation-induced stress. In the longer term, repeated disturbance can affect individual fitness and reproductive success and, consequently, population dynamics. While most studies still focus on individual responses and evidence for effects at higher level remains comparatively scarce (and sometimes contradictory), various authors suggest that individual impacts are likely to translate into negative effects for population and ecosystem functioning (Brambilla et al., 2004; Gaynor et al., 2018; Neumann et al., 2009; Patthey et al., 2008).

As concerns soil and vegetation, the picture that emerges is similarly consistent: negative impacts have been documented across all activity types reviewed, ranging from soil degradation associated with hiking and cycling (Kuwaczka et al., 2023; Marion & Leung, 2001), to the sharp decline in plant biodiversity on cliffs during climbing route opening (Morales-Armijo et al., 2024), to ecosystem alteration on ski piste (Rolando et al., 2007). Notably, the most substantial impacts tend to occur at the first trampling or mechanical event (Cole, 1987; Kuwaczka et al., 2023). While trails are generally associated with species loss and the introduction and spread of alien species and pathogens (Chisholm & McCune, 2024), it has also been reported that trail edges can locally foster greater plant species richness by creating colonisation opportunities for generalist and weakly competitive species, including some Alpine taxa (Wedegärtner et al., 2022). However, these findings do not offset the broader ecological risks associated with trampling and the potential loss of rare or disturbance-sensitive species, but rather highlight the importance of site-specific assessments for effective management decisions.

For specific activities, it is instructive to compare hiking (the most widespread of all) with mountain biking and trail running, which are rapidly growing in popularity. The types of impact

in terms of wildlife disturbance caused by the three activities are broadly the same. The final magnitude depends on a complex interrelation of modulating factors (Tablado & Jenni, 2017) and is highly context- and species-specific (Mitterwallner et al., 2021). For example, vocal, large groups of hikers generate the highest probability of flight initiation in comparative experiments, while silent runners and cyclists tend to produce longer vigilance times (Zeller et al., 2024). The rapid approach of these latter categories can reduce the distance at which animals detect them, increasing the probability of abrupt and energy-costly flight responses (Tablado & Jenni, 2017), while the longer distances covered increase their spatial reach and the total number of animals disturbed per unit of time (Kuwaczka et al., 2023; Taylor & Knight, 2003). In any case, three points clearly emerge from the literature:

1. Although commonly considered a low-impact activity, hiking negatively affects wildlife, and its effects are particularly relevant due to the large and rapidly increasing number of people visiting natural areas, and are substantially amplified in the presence of dogs (Hennings, 2016; Steven et al., 2011).
2. The proliferation of electric mountain bikes is expected to amplify the disturbance caused by cyclists on both wildlife and vegetation, with higher speed, the ability to access more remote high-altitude areas, and the removal of fitness barriers increasing both the spatial extent and the number of practitioners (Kuwaczka et al., 2023; Mitterwallner et al., 2021).
3. The surge of competitive trail running mass events concentrates thousands of participants on narrow paths within short time windows that frequently extend into nighttime, negatively affecting the behavioural and reproductive output of animals (Marchand et al., 2025) and causing concentrated soil degradation and plant trampling that persists long after the event (Ng et al., 2018).

Winter recreational activities deserve particular attention because they operate precisely when Alpine biodiversity is under the greatest physiological stress. Species remaining active in winter must cope with conditions of reduced food availability, increased thermoregulatory costs, and impeded movement in snow. Any additional energy expenditure triggered by human disturbance therefore erodes reserves that are already critically limited. Winter recreational activities not only cause direct disturbance (Arlettaz et al., 2007), but also generate a significant reduction in the habitat effectively available to animal species in the vicinity of ski resorts and backcountry routes (Coppes et al., 2017). In the case of ski touring, they create spatial and temporal overlaps with the narrow dawn-dusk foraging windows that are critical for tetraonid survival, affecting food absorption and potentially increasing winter mortality (Jäger et al., 2020). Ski piste infrastructure also has a negative impact on vegetation,

reducing both biomass and species richness with cascading consequences on ecosystem health (Casagrande Bacchiocchi et al., 2019; Rolando et al., 2007). Moreover, the prospect of further upward expansion of ski resort infrastructure under climate change scenarios is projected to massively raise the overlap between skiable terrain and Alpine climate refugia (Roseo et al., 2025), posing major conservation concerns.

Finally, a cross-cutting issue that was not directly addressed by the present review, but that emerges consistently from the management literature, concerns visitor awareness. Survey research shows that the majority of recreationists across all activity types do not perceive themselves as causing harm to the natural environments they visit (Cremer-Schulte et al., 2017; Taylor & Knight, 2003), even in the presence of explicit conservation information (Walter et al., 2024). This gap between perceived and actual impact represents a crucial practical barrier to effective visitor management, since voluntary compliance with access restrictions, temporal limitations, and zoning measures cannot be assumed where awareness is absent.

1.5 Conclusions

The bibliographic analysis presented in this section consistently confirms that nature-based recreational activities generate measurable negative impacts on Alpine biodiversity. While the magnitude and nature of these effects vary considerably depending on the context, species and activity, several key findings and management implications emerge:

- Even low intensities of recreational activity can produce negative effects on both fauna and flora: the precautionary principle is therefore particularly relevant, especially in areas hosting rare, endemic, or threatened species.
- The intensity level and cumulative dimension of disturbance tend to amplify negative impacts: multiple activities overlapping in space and time generate pressures that cannot be reduced to their individual components and whose total effect may exceed what studies on single impact suggest.
- The potential for cascade effects must always be considered: alterations to vegetation, soil, or key species can trigger indirect consequences that propagate through ecological networks, ultimately affecting ecosystem functioning in ways that extend well beyond the initial disturbance event.
- For vegetation, the first trampling event and the opening of new routes or trails cause the strongest damage: preventing initial disturbance is thus substantially more effective than managing it after it has been established.

- For wildlife, the most disruptive events are those that are sudden and unpredictable: off-trail and nighttime activities consistently produce stronger stress responses than on-trail, daytime equivalents, and are particularly critical during winter.
- Recreation reduces effective habitat availability for wildlife in both spatial and temporal dimensions: human presence creates a landscape of fear that can confine animal activity to suboptimal locations and hours.
- Impacts are highly context- and species-specific and depend on a complex interrelation of modulating factors: reliable monitoring and data are crucial to ensure that management measures are based on site- and species-specific assessments rather than generalized assumptions.
- Climate change acts as a compounding factor: beyond its direct effects on Alpine biodiversity, it changes how, where, when and by how many people recreational activities are performed, determining additional pressure on sensitive environments.
- Visitor awareness represents a structural management challenge: the majority of practitioners do not perceive themselves as causing harm and voluntary compliance with conservation measures cannot be assumed even in the presence of sustained and targeted communication efforts.

2 Analysis of different methodologies for measuring impacts and responses

2.1 Case study 1: Mont Avic Natural Park

2.1.1 *Impacts on biodiversity*

2.1.1.1 *Introduction*

The aim of this study is to systematically and thoroughly analyse the intensity and spatial distribution of nature-based activities (NBAs) within the Mont Avic Natural Park (PNMA), as well as to attempt to assess the potential and actual effects of anthropogenic pressure on biodiversity, with particular reference to the fauna species most sensitive to disturbance. The study is based on an integrated approach that combines the analysis of human use along the park's official trail network with the analysis of data on the presence of certain wildlife species, identified as valid biological indicators for this analysis. The analysis is differentiated by seasonality and also includes an assessment of habitat fragmentation in order to understand the possible interference between recreational use of the area and conservation objectives. The specific objectives of this study can be summarised as follows:

- to identify and quantify the current intensity of NBA within the territory of the Mont Avic Natural Park
- to assess the potential impacts of NBA on biodiversity, with particular reference to fauna species sensitive to disturbance
- to assess the degree of habitat fragmentation caused by the trail network and anthropogenic pressure

2.1.1.2 *Study area*

The Mont Avic Natural Park (Aosta Valley, Italy) was established in 1989 to preserve one of the wildest areas in the region: the upper basin of the Chalamy stream in the municipality of Champdepraz. The park was first expanded in 2003 into the adjacent Champorcher Valley, thus reaching the north-eastern borders of the Gran Paradiso National Park. In 2023, a second expansion extended the protected area to the upper part of the Clavalité Valley, in the municipality of Fénis. Today, the park covers an area of approximately 7,300 hectares and

ranges in altitude from around 1,000 metres in the 'lowest' areas to 3,185 metres at the summit of Mont Glacier. Mont Avic, the spectacular serpentine peak that gives the park its name, is just over 3,000 metres high.

The flora and vegetation of the Park are deeply influenced by the presence of a large number of lakes and small wetlands, as well as abundant outcrops of serpentinite, rocks that give rise to poor, shallow soils. The fauna of the Park, on the other hand, is characterised primarily by the high number of insect species present, due to the considerable environmental variety of the protected area: to date, over 1,100 species of butterflies have been reported, 22 species of Ditiscidae and Eloforidae beetles linked to wetlands and 111 species of forest phytophagous beetles, 32 of which have never been reported before in the Aosta Valley.

Among the vertebrates, all the mammals of the mountain environment common in the region are present, including the ibex, chamois and mountain hare. There are over 120 species of birds, more than 90 of which are nesting birds. Birds of the park include the golden eagle, goshawk, rock ptarmigan, black grouse, rock partridge, Tengmalm's owl, black woodpecker, rock bunting, red-billed chough and nutcracker.

As all protected natural areas, the Mont Avic Natural Park has established rules of conduct, which can be found here: <https://montavic.it/norme-di-comportamento/>. Below are those that are most closely related to this discussion.

Dogs:

- Dogs are allowed in the park, even in winter, only if they are on a leash and only if they walk along the marked paths

Trails – excursions:

- It is not permitted to leave the marked trails. This prevents widespread disturbance to animals and damage to vegetation due to trampling
- To reach the summits of Mont Avic, Mont Torretta, Bec Costazza and Roèse di Bantze, it is permitted to leave the marked trails and follow the normal routes to these peaks
- Even in winter, it is compulsory to follow the marked trails so as not to disturb animals struggling against the cold and hunger

Skiing – snowshoeing (Figure 2.1 A):

- When the ground is covered with snow, it is permitted to leave the trails on foot, with snowshoes or skis, but only in certain areas of the Park

Transport and aircraft:

- Motorised vehicles, boats, hang gliders, paragliders or similar, and drones may not be used

Mountain bikes (mtb) and riding animals (Figure 2.1 B):

- Mountain bikes and riding animals are permitted only on certain trails and always with respect for walkers
- Mountain bikes and horses may only use the designated trails

Climbing and mountaineering (Figure 2.1 B-C):

- Climbing and mountaineering are permitted only in certain areas or on certain trails

Drones and other aircraft:

- The use of drones is prohibited in the Park, as is flying, taking off and landing with any type of aircraft, whether motorised or gliding

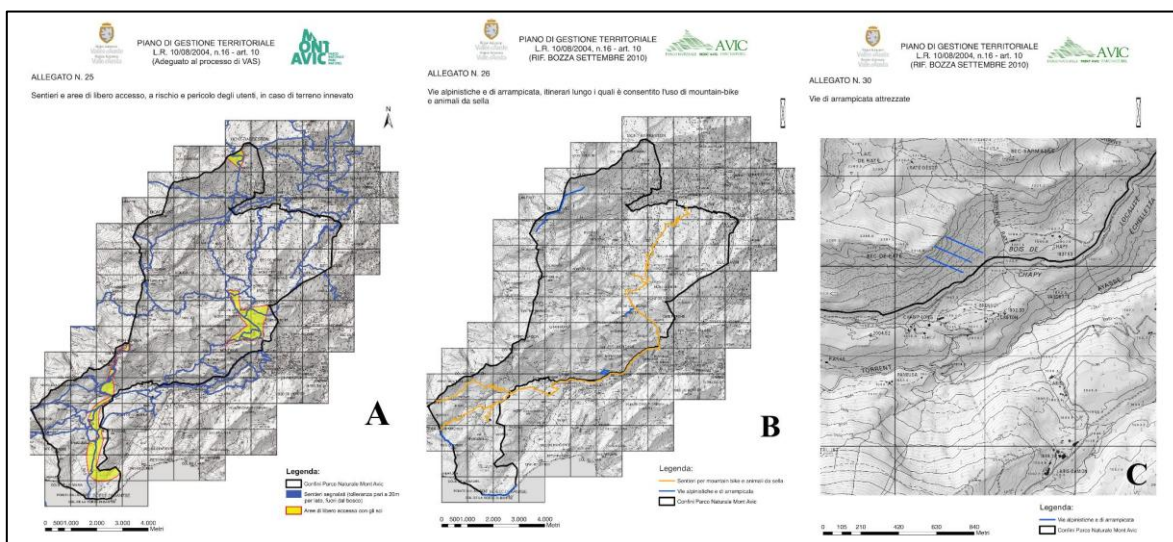


Figure 2.1 Areas where certain NBAs are permitted (A: trails and areas where activities on snow covered ground are permitted; B: mountaineering routes, itineraries where the use of mountain bikes and riding animals is permitted; C: equipped climbing routes).

2.1.1.3 Materials and methods

General methodological framework

The methodology adopted is based on the integrated analysis of human visitation data and wildlife data for the period between 2019 and 2024. In particular, the following were analysed:

- data on human passage and presence along the Park's official trail network
- data on the presence of certain wildlife species identified as indicators of sensitivity to human disturbance
- data on habitat fragmentation caused by the effects of NBA on the Park's trail network

The analysis was conducted across the entire park, divided into the valley sectors of Champdepraz, Champorcher and Fénis (the latter included within the boundaries of the Mont Avic Natural Park from May 2023).

Anthropic attendance data

In order to estimate visitor numbers along the trail network and define the intensity of NBA in different seasons, data available for the period 2019–2024 was collected and processed. Following discussions with Park staff, two main types of data were identified:

1. Data collected by Mont Avic Natural Park rangers

The data analysed was not collected *specifically* for this project, but was recorded during routine surveillance and monitoring activities, when park rangers record the presence of hikers and wildlife observations. The latter are archived and managed via the iNaturalist platform, which allows data to be organised and processed by associating it with precise geographical coordinates. Processing data that was not collected *specifically for this purpose* has necessarily entailed some difficulties. For example, wildlife and human presence observations are not always simultaneous, and the 'zero' data is not always reported. The analyses below cannot therefore be entirely exhaustive, but they do provide a picture of the current situation that is useful for this study and can be verified in subsequent targeted research projects. In addition to assessing the possible impact of NBA on biodiversity, the analysis of the data collected so far also aims to understand how to use the data already available and what guidance to provide to park rangers for future collection, so as to make the most of institutional data collection work and not place an additional burden on the performance of institutional tasks.

2. Data from automatic counting systems (eco-counters)

Four automatic eco-counters are installed in the park, located along the most frequented sections of the trail. The monitoring stations are called CORT, CREST, MISERIN and SERVAZ. Passage data is recorded continuously and managed using Eco-Visio.net software.

Data collected by the rangers

The visitor data collected by park rangers has been preliminarily organised into a standardised format in order to make it comparable and usable for subsequent spatial and temporal analyses. The datasets derived from iNaturalist have been structured into tables divided by valley (Champdepraz, Champorcher and Fénis) and by year.

For each official trail, information was extracted on (Table 2.1):

- number of people contacted on a monthly basis
- total number of observations per year

MONTH/PATH	7	A2	7b	7c	8b	8c	8	9b	9c	9d	9a	10	10c	10d-102	7	A2	7a	MONTH TOTAL
January	Miserin-Col de la Roëse di Banzte	Dondena-Miserin	P. Lai-Col Fenêtre	Pian di Lai-Col Fénis-Col Pontonnet	Pian Enseta-Col Moussaillon	Pian Enseta-Col Fussy-Mt. Glacier	Pian Enseta-Lac e Col Pontonnet	Mont Blanc-Dondena	Muffè-Vermouille-Raty-Glasset Dondena	Bivio con 10 Vernouille désot	Vardette-Chapy-Lac Raty	Mont Blanc-Col du lac Blanc	Muffè-Col de la Croix	Col de la Croix-Col de Cima Piana	Dondena-Bese-Miserin	Miserin-Col Fenêtre	Miserin-Lac Noir	293
February		12						113	11		6	154	9					527
March								228	33		7	215						483
April		44										255	19					318
May									5			72	9					86
June	1	520				4		1	69			1041	23		76	2		1737
July	3	310	10	4		48						1580	48	8	3			2014
August	2	325		7		39			39			1176			162	27		1777
September	2	197	28			25						793	19		16	14		1094
October		21						1	13		2	604	30	8				679
November								63			3	376	4	2				448
December								46	3	7		231						287
TOTAL	7	1429	38	11		116		795	178	7	18	6664	161	18	257	43		9743

Table 2.1 Number of people registered by the rangers along the paths

The data were then aggregated by season (winter, spring, summer and autumn) and divided into categories of visitor intensity according to the following scheme:

- **No data:** no data available
- **Very low:** 0–100 visits
- **Low:** 101–500 visits
- **Medium:** 501–1,000 passages
- **High:** 1,001–2,500 visits
- **Very high:** over 2,500 visits

The classes were established in the absence of specific bibliographical references, but taking into account the minimum and maximum numbers of visitors to the PNMA over the years and with a view to dividing them into homogeneous classes (Table 2.2) The choice to operate in classes of aggregated data also makes it possible to reduce the error potentially caused by the different sources of the data in terms of how it was collected. Future studies, aimed at improving techniques for monitoring visitor numbers, collecting related data, and trying to find the carrying capacity relative to visitors that the protected area can support, will be able to provide more accurate information on these aspects.

The above classification has been applied to each official trail, with temporal aggregation by year for the period 2019–2024 for the Champdepraz and Champorcher sectors and for the period 2023–2024 for the Fénis sector, which was not previously included in the Park (Table 2.3, Figure 2.2).

CLASSIFICATION OF TRAILS USAGE	
Class	Range passages
NULL	0
VERY LOW	1-100
LOW	101-500
MEDIUM	501-1000
HIGH	1001-2500
VERY HIGH	> 2500

Table 2.2 Classes of presences

MONT BLANC-COL DU LAC BLANC				
Season	Month	Path n. 10	Class per month	Class per season
Winter	January	494	LOW	HIGH
	February	505	MEDIUM	
	March	157	LOW	
Spring	April	228	LOW	MEDIUM
	May	205	LOW	
	June	274	LOW	
Summer	July	1280	HIGH	VERY HIGH
	August	1749	HIGH	
	September	312	LOW	
Autumn	October	246	LOW	HIGH
	November	807	MEDIUM	
	December	201	LOW	
	TOTAL	6458	VERY HIGH	

Table 2.3 Example of human presences on Path n. 10 - CHAMPORCHER- 2024

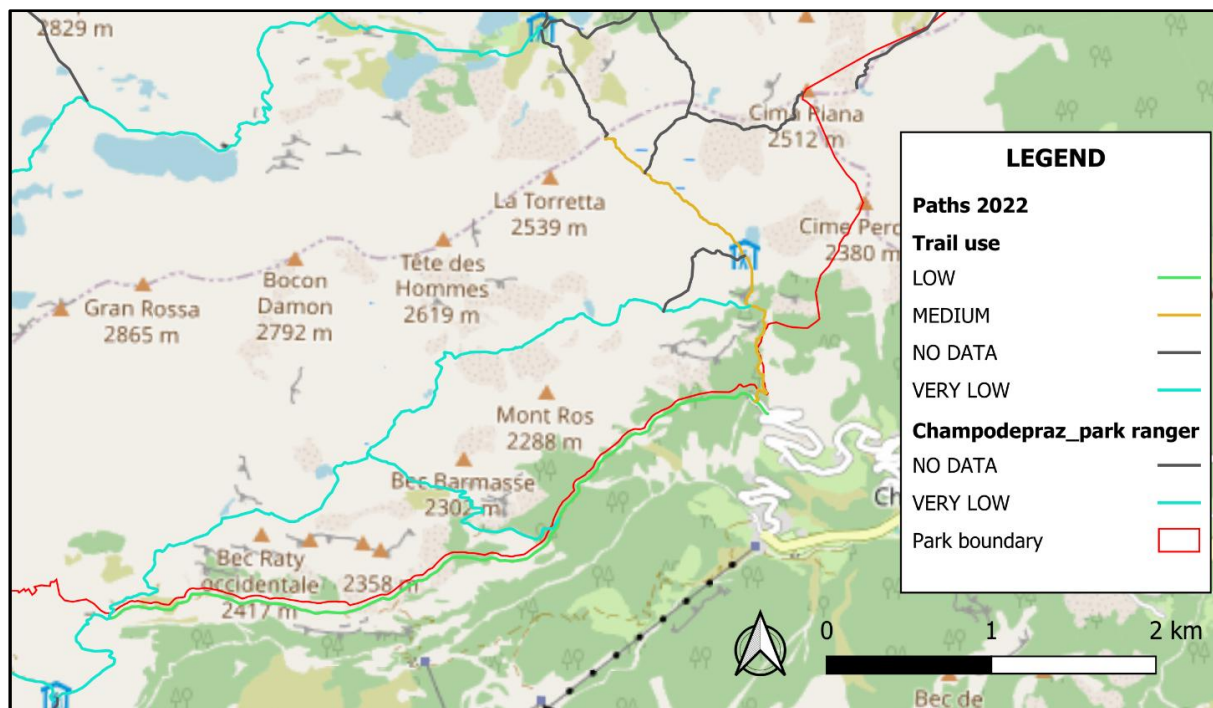


Figure 2.2 Example of trail use - CHAMPDEPRAZ - 2022

Data from eco- counters

The people counters installed in the PNMA consist of plate sensors positioned along the trails and located a few centimetres below the walking surface. The passage of people or animals generates a change in pneumatic pressure that is recorded by the sensor. The detection system does not allow for distinguishing between different types of traffic (hikers, cyclists, wildlife, livestock) or direction of travel; however, it guarantees continuous recording 24 hours a day and in all seasons, representing an important source of quantitative and objective data.

In any case, the strategic positioning inherently limits the number of counts other than human traffic. The counting stations are located as follows (Figure 2.3):

- **Crest:** Champdepraz Valley, immediately outside the park boundaries, along official trail no. 7b, at an altitude of 1,350 m.
- **Servaz:** Champdepraz Valley, immediately inside the park boundaries, along official trail no. 5c at an altitude of 1,530 m.
- **Cort:** Champorcher Valley, within the park boundaries, along official trail no. 10 at an altitude of 1,800 m.
- **Miserin:** Champorcher Valley, within the park boundaries, upstream of the lake of the same name, along the official trail no. A2 at an altitude of 2,620 metres.

The daily data recorded by each eco-counter (Figure 2.4) were aggregated on an annual basis (2019–2024) and then reworked on a seasonal basis. In this case too, the same classification into classes of visitor intensity was used as for the data collected by the rangers (Table 2.4; Table 2.5).

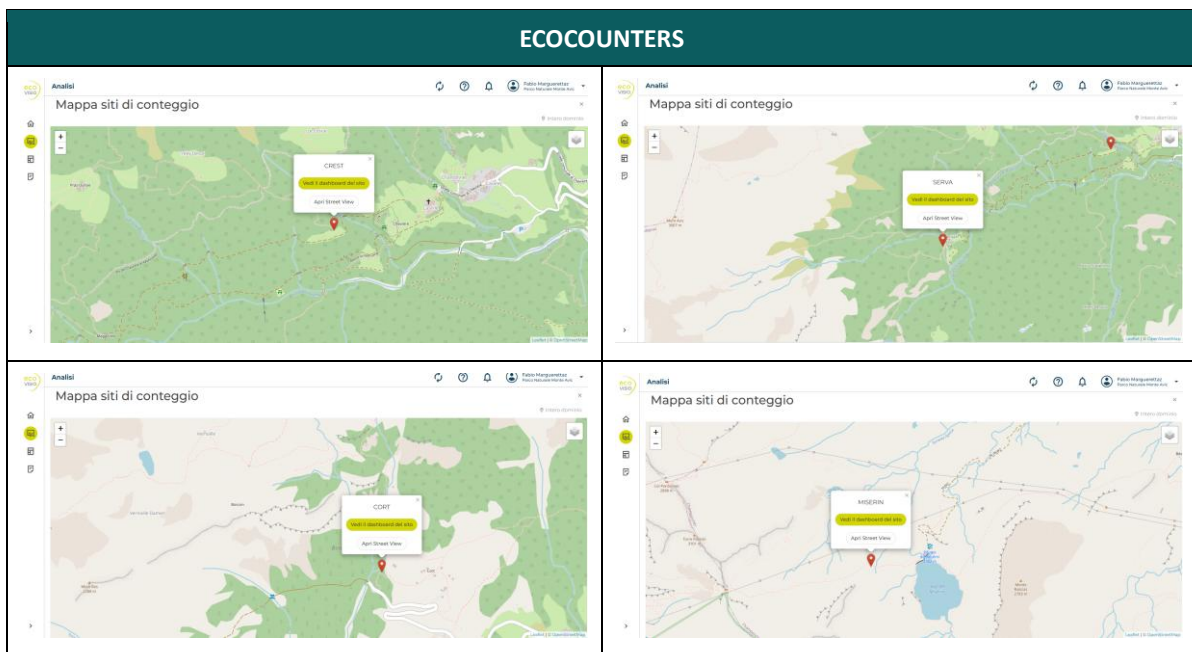


Figure 2.3 The four ecocounters of the Mont Avic Natural Park

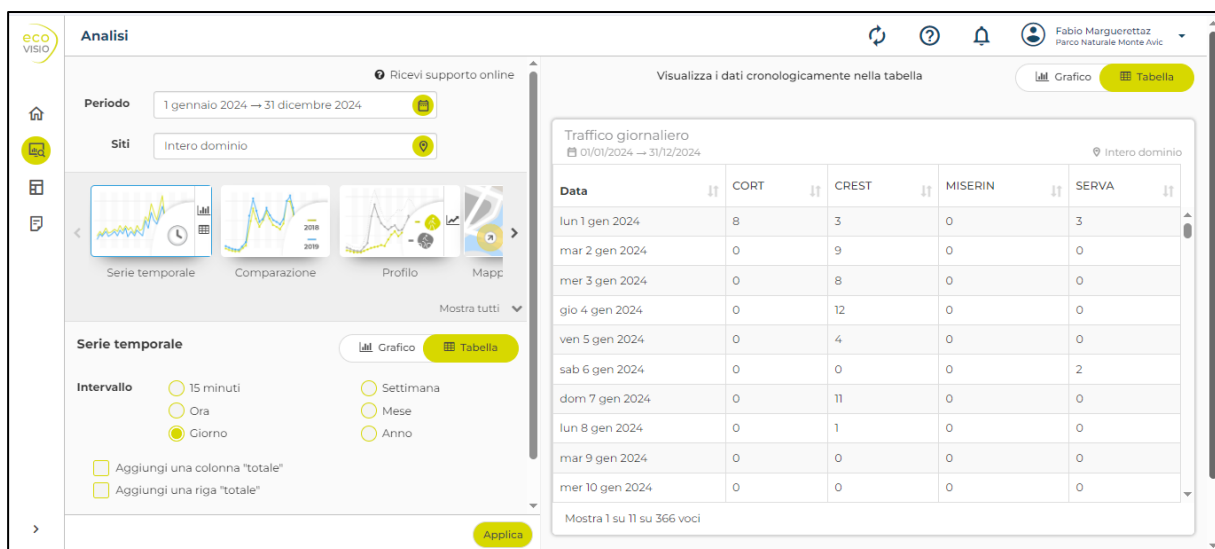


Figure 2.4 The daily data recorded by the four eco-counter

CORT ECO-COUNTER				
Season	Month	Path n. 10	Class per month	Class per season
Winter	January	8	VERY LOW	MEDIUM
	February	723	MEDIUM	
	March	24	VERY LOW	
Spring	April	408	LOW	VERY HIGH
	May	798	MEDIUM	
	June	2551	VERY HIGH	
Summer	July	6330	VERY HIGH	VERY HIGH
	August	9601	VERY HIGH	
	September	3014	VERY HIGH	
Autumn	October	900	MEDIUM	MEDIUM
	November	0	NO DATA	
	December	0	NO DATA	
TOTAL		24357	VERY HIGH	

Table 2.4 Example of the Cort eco-counter

Values				
Etichette di riga	Somma di CORT	Somma di CREST	Somma di MISERIN	Somma di SERVA
AUTUMN				
DECEMBER	0	0	0	0
NOVEMBER	0	0	0	0
OCTOBER	900	53	20	90
SPRING				
APRIL	408	0	0	134
JUNE	2551	271	0	653
MAY	798	111	0	439
SUMMER				
AUGUST	9601	780	1629	2329
JULY	6330	510	443	1468
SEPTEMBER	3014	378	1182	737
WINTER				
FEBRUARY	723	79	0	74
JANUARY	8	65	0	12
MARCH	24	5	0	1
Totale complessivo	24357	2252	3274	5937

Table 2.5 Pivot table with the monthly passages on the four eco-counter

Cartographic processing

All analyses and cartographic processing were carried out using the open-source GIS software QGIS, which enabled the management, analysis and representation of geospatial data in the ED50 / UTM Zone 32N cartographic reference system.

In the first phase, the official trail network of the Mont Avic Natural Park was verified and digitised, creating shapefiles with linear geometry divided by valley (Champdepraz, Champorcher and Fénis) and assigning each segment the official trail identification number. Subsequently, each trail segment was associated with usage data, organised by year and intensity class. From a cartographic representation point of view, a colour classification differentiated by usage class was adopted in order to facilitate the interpretation of thematic maps (Figure 2.5).

Similarly, point geometry shapefiles were created to represent the location of the eco-counters and to associate each station with usage data organised according to the same temporal and classification structure (Figure 2.6).

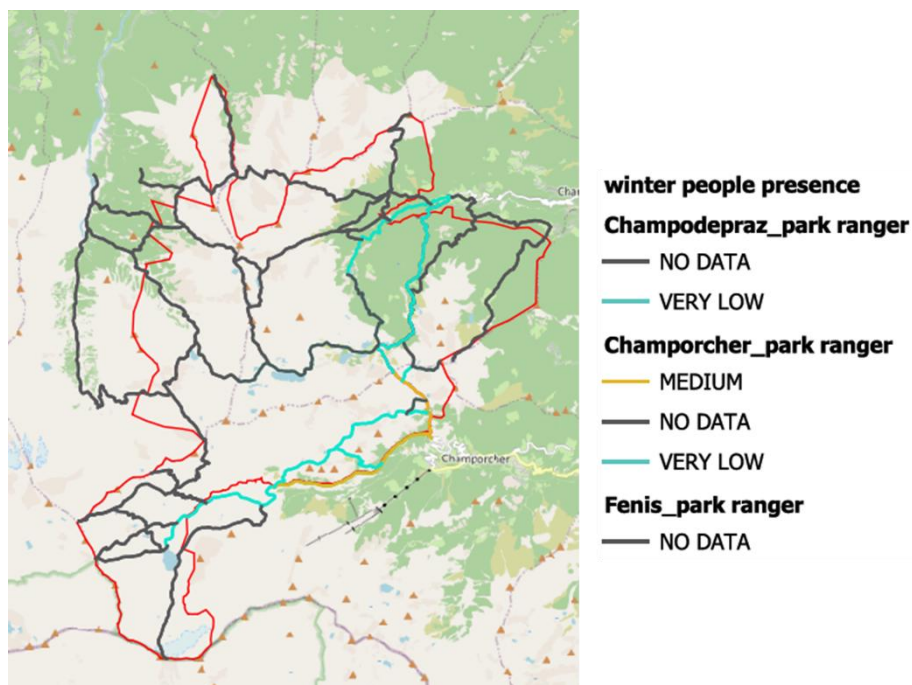


Figure 2.5 Classification of trails based on tourist presence

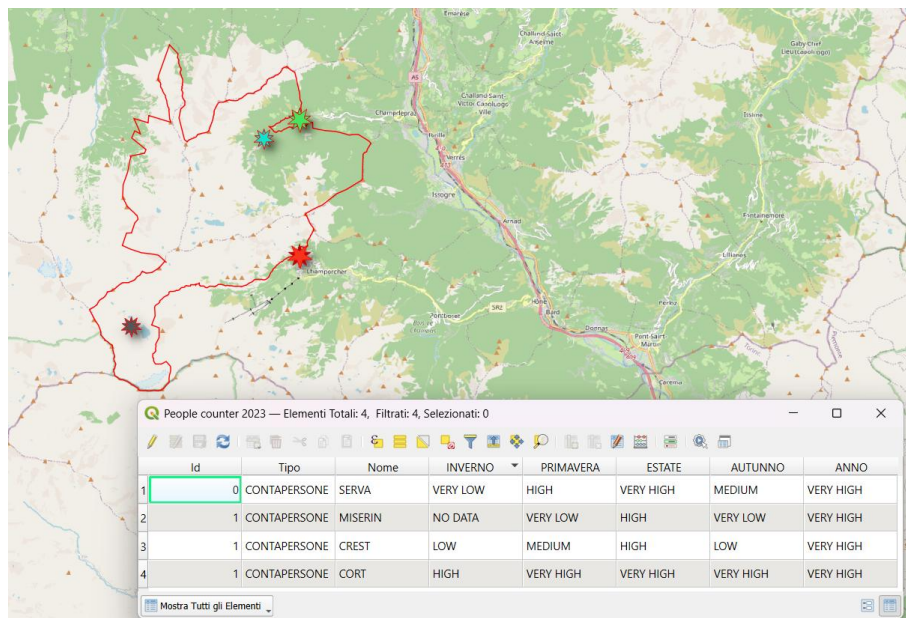


Figure 2.6 The tourist presence classes for the eco-counters

Identification of biological indicators - Species selection criteria

In order to assess the impact of NBA on biodiversity, a protocol was defined to identify fauna species that could be used as biological indicators (Figure 2.7). The analysis was limited to vertebrates and began with an examination of the official fauna checklists of the Mont Avic Natural Park.

For each species, the degree of vulnerability was assessed, as defined in the main conservation regulations and instruments, with particular reference to:

- Habitat Directive (Annex II)
- Birds Directive (Annex I)
- Bern Convention and/or Bonn Convention
- Red Lists (categories CR, EN, VU)
- National and regional wildlife protection regulations

The availability of georeferenced presence data was also verified for each species. Only species that successfully met all selection criteria were considered suitable as biological indicators in this study (Figure 2.7).

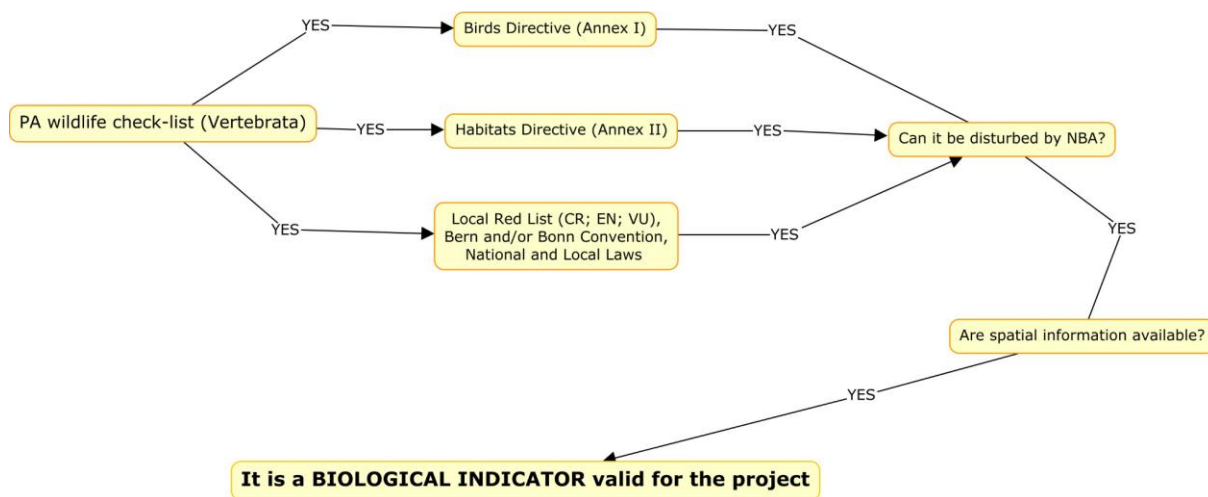


Figure 2.7 Flow chart for selecting target species

Based on the protocol described above, the following indicator species were selected:

- Chamois *Rupicapra rupicapra*
- Ibex *Capra ibex*
- Rock ptarmigan *Lagopus muta*
- Black grouse *Lyrurus tetrix*

Analysis of wildlife presence data and interference with NBA

Data on the presence of indicator species are derived from observations recorded by park surveillance staff using the iNaturalist system (Figure 2.8). These data were organised into time series consistent with those used for the analysis of human frequentation (period 2019–2024) and aggregated by season. In view of the absence of a standardised method for recording the number of individuals observed, all reports were treated as presence/absence data, without assigning quantitative values relating to numerical consistency.

For example, in the table below, you can see records in which rangers recorded both the species observed and the number of individuals and, in some cases, even the sex, but most of them only report the species. Therefore, during data processing, each observation was assigned a value of 1. Thus, in Table 2.1, Winter 38 means that the chamois was encountered 38 times, regardless of the number of individuals recorded.

A	B	C	D	E	F	G	H	I	J	K	L	M
id	observed_on_string	observed_on	anno	mese	giorno	stagione	user_login	description	latitude	longitude	coordinates_obscured	scientific
1	195555229	2024-01-02 09:59:51	2024-01-02	2024	1	2	inverno	giadacignetti	45.6241401659	7.5822196528	true	Rupicapra
2	195558237	2024-01-02 11:08:58	2024-01-02	2024	1	2	inverno	giadacignetti	45.6221694829	7.5686081126	true	Rupicapra
3	195648055	2024-01-03 10:22:33	2024-01-03	2024	1	3	inverno	annafoieri	45.6212037026	7.5792306662	true	Rupicapra
4	195649360	2024-01-03 11:01:03	2024-01-03	2024	1	3	inverno	annafoieri	45.6199883187	7.5622770935	true	Rupicapra
5	195650056	2024-01-03 11:20:06	2024-01-03	2024	1	3	inverno	annafoieri	45.6255399909	7.580733709	true	Rupicapra
6	196413320	2024-01-12 09:53:38	2024-01-12	2024	1	12	inverno	annafoieri	45.6348557912	7.6018118486	true	Rupicapra
7	196908156	2024-01-17 12:36:14	2024-01-17	2024	1	17	inverno	annafoieri	45.6206378712	7.5795991346	true	Rupicapra
8	197060866	2024-01-19 14:53:00	2024-01-19	2024	1	19	inverno	giadacignetti	45.6219334362	7.5842899829	true	Rupicapra
9	197677755	2024-01-27 10:46:25	2024-01-27	2024	1	27	inverno	annafoieri	45.6291838268	7.5895189494	true	Rupicapra
10	197677792	2024-01-27 10:48:07	2024-01-27	2024	1	27	inverno	annafoieri	45.6294705687	7.588763237	true	Rupicapra
11	197776980	2024-01-28 09:59:31	2024-01-28	2024	1	28	inverno	giadacignetti	45.6427167711	7.5974230841	true	Rupicapra
12	198044995	2024-01-31 11:21:02	2024-01-31	2024	1	31	inverno	annafoieri	45.6373226927	7.6056692004	true	Rupicapra
13	198198994	2024-02-02 10:36:00	2024-02-02	2024	2	2	inverno	giadacignetti	45.6246464048	7.5697490573	true	Rupicapra
14	198289390	2024-02-03 10:00:00	2024-02-03	2024	2	3	inverno	pietro_ruggieri	45.6302946796	7.5469036773	true	Rupicapra
15	198475613	2024-02-05 10:43:47	2024-02-05	2024	2	5	inverno	annafoieri	45.6206181737	7.5619035959	true	Rupicapra
16	198475955	2024-02-05 10:52:16	2024-02-05	2024	2	5	inverno	annafoieri	45.617595462	7.508507706	true	Rupicapra
17	198178054	2024-02-13 10:12:19	2024-02-13	2024	2	13	inverno	annafoieri	45.6199693245	7.5796155632	true	Rupicapra
18	199350297	2024-02-15 11:09:29	2024-02-15	2024	2	15	inverno	annafoieri	45.6315996338	7.5978871062	true	Rupicapra
19	199540517	2024-02-08 09:55:22	2024-02-08	2024	2	8	inverno	giadacignetti	45.6842816345	7.5910417736	true	Rupicapra
20	200261790	2024-02-24 10:45:53	2024-02-24	2024	2	24	inverno	alessandrodurando1	45.6233237025	7.5838588178	true	Rupicapra
21	201241383	2024/01/29 9:27 AM	2024-01-29	2024	1	29	inverno	alessandrodurando1	45.631372588	7.6198719463	true	Rupicapra
22	201241388	2024/01/30 8:22 AM	2024-01-30	2024	1	30	inverno	alessandrodurando1	45.631372588	7.6198719463	true	Rupicapra
23	202807430	2024-03-17 14:00:37	2024-03-17	2024	3	17	inverno	giadacignetti	45.634508358	7.6033816114	true	Rupicapra
24	203862726	2024-03-25 09:21:56	2024-03-25	2024	3	25	inverno	giadacignetti	45.6832023294	7.5886647535	true	Rupicapra
25	206030343	2024-04-05 08:29:50	2024-04-05	2024	4	5	primavera	giannabosio	45.6835007136	7.5916041193	true	Rupicapra
26	206953004	2024-04-13 16:09:47	2024-04-13	2024	4	13	primavera	annafoieri	45.6224910476	7.5763721019	true	Rupicapra
27	207388505	2024-04-15 15:36:55	2024-04-15	2024	4	15	primavera	giadacignetti	45.6862170253	7.6032837108	true	Rupicapra
28	208874629	2024-04-20 11:33:01	2024-04-20	2024	4	20	primavera	pietro_ruggieri	45.6340054903	7.5917230546	true	Rupicapra
29	208908403	2024-04-23 09:09:38	2024-04-23	2024	4	23	primavera	robertofacchini	45.6833383913	7.5914809853	true	Rupicapra

Figure 2.8 Example of data collected by the rangers in iNaturalist

The data were then converted into point geometry shapefiles and represented cartographically. A dedicated cartographic layout was prepared for each season in order to allow comparative analyses between the spatial distribution of human presence and the presence of indicator fauna species.

2.1.1.4 Results and Discussion

The complete results of the annual analyses are reported for each species studied in Annex 1. The data refer to the entire territory of the Park. The main results and the discussion are summarised below.

Chamois *Rupicapra rupicapra*

The graph below (Figure 2.9) illustrates the seasonal distribution of *Rupicapra rupicapra* observations during the study period 2019–2024. The trend of the observations recorded by the park rangers shows marked interannual and seasonal variability. Between 2019 and 2020, there was a general decrease in observations in all seasons, with the exception of autumn, which showed a significant increase; this increase was followed by a decrease in 2021. In the transition from 2020 to 2021, the winter, spring and summer seasons show increases of varying degrees. In 2022, there is a decline in observations in the winter season and, more markedly, in the spring season, accompanied by an increase in the summer and autumn periods. In 2023, there was a decrease in contacts in all seasons, with the sole exception of spring, which showed an increase in observations. Finally, in 2024, there was a general decrease in observations in all seasons considered.

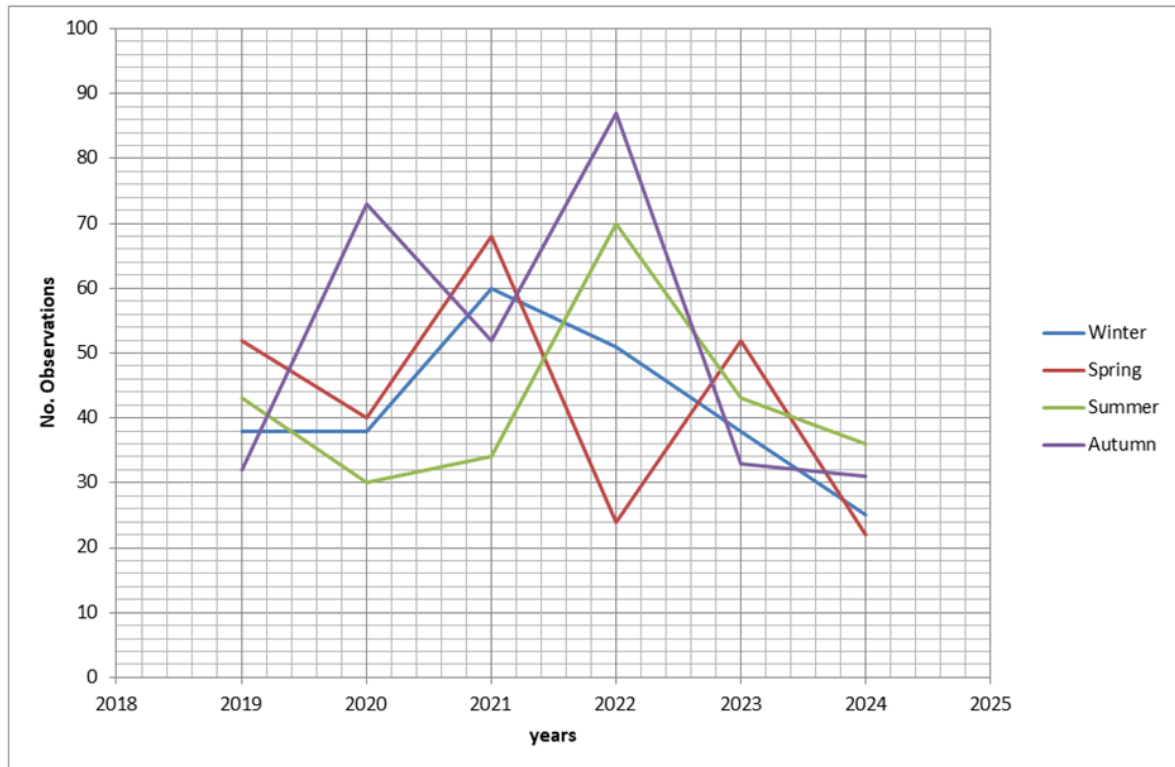


Figure 2.9 Seasonal distribution of chamois observations in 2019–2024 period.

The analysis of data collected between 2019 and 2024 for the chamois (*Rupicapra rupicapra*) shows seasonal altitudinal variation consistent with the behaviour of the species. In winter, chamois reach lower altitudes, with lower limits recorded between 1250 and 1500 m, probably in response to variations in snow cover during the years studied and, consequently, to food availability and the need to reduce energy costs. As spring progresses and especially in summer, a gradual ascent to higher altitudes is observed, with upper limits recorded reaching 2800–2900 m, corresponding to the alpine level. This behaviour appears to be functional to the exploitation of high-altitude pastures and to avoid high summer temperatures at lower altitudes. In autumn, there is a gradual descent to average altitudes of around 1900- 2000 m.

Analysis of spatial distribution shows that use of the park's territory is fairly stable over time. The Champorcher sector, with particular reference to the southern part of the park, is consistently the area with the highest concentration of the species during the winter, spring and autumn seasons. The central sector of the park is used more in summer, when the species moves to higher altitudes and distribution is more homogeneous across the valleys.

Analysis of data on human use of the park's trail network in relation to the seasonal distribution of the species shows a possible inverse correlation between the presence of

chamois and the intensity of trail use. In fact, in all the years considered, chamois sightings are concentrated:

- along trails with no or very low use
- in areas far from the official trail network
- near the park boundaries, particularly in the southern part of the Champorcher area in winter, spring and autumn, always in areas with low visitor numbers

On the contrary, trails with medium, high or very high visitor numbers tend to be avoided, especially in summer, when human pressure reaches its peak. The rare sightings observed near trails with medium visitor numbers could be interpreted as episodes of tolerance, but the available data do not allow for precise assessments sufficient to change the general trend described.

Overall, the data analysed indicate that the Park's chamois population adopts a spatial strategy based on seasonal altitudinal movement and seems to prefer environments and territories with less anthropogenic disturbance. The low-traffic areas coincide with the functional areas for the species during most of the year, just as the summer expansion to higher altitudes tends to be recorded while maintaining a clear separation from the main hiking trails.

Considering the physiological seasonal redistribution of the species, the data collected during the 2019-2024 analysis period show that the species probably maintains a well-defined spatial selection, preferring areas characterised by low human accessibility and less disturbance.

***Alpine ibex* Capra ibex**

The graph showing observations of *Capra ibex* in the study period highlights that summer consistently represents the season with the highest number of contacts, while in other seasons the values are significantly lower, generally limited to a few units and in some cases zero (Figure 2.10). The overall trend shows marked interannual and seasonal variability. Between 2019 and 2020, there was a slight increase in observations in winter, spring and autumn, compared to a sharp decrease in summer. In 2021, winter data remained stable, with a slight decrease in spring and an increase in summer and autumn. In 2022, there was a marked increase in winter and, above all, summer observations,

representing the highest value for the entire period, accompanied by an increase in autumn and a decline in spring. In 2023, there was a decrease in winter, summer and autumn, compared to an increase in spring. Finally, in 2024, there was a general decline in observations in all seasons, with a slight recovery in the summer period.

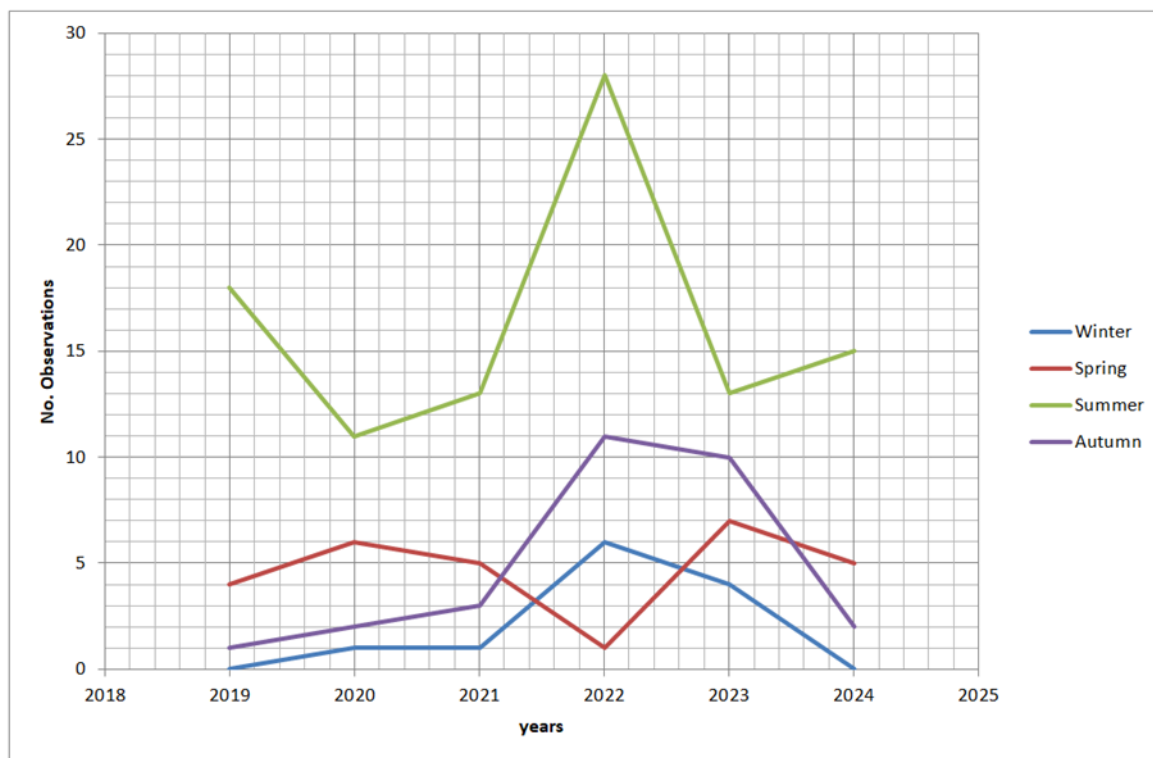


Figure 2.10 Seasonal distribution of Alpine ibex observations in 2019–2024 period.

Overall, for the period under analysis (2019–2024), data on the presence of Alpine ibex show a marked preference for high-altitude environments, with use of the territory strongly influenced by seasonality. Sightings are generally scarce or absent in winter, while they increase progressively in spring and reach their annual peak in summer, when the species permanently occupies alpine grasslands and higher rocky environments.

The altitudinal range recorded in park ranger observations shows a clear seasonal pattern: in winter and in the intermediate seasons, observations are made at lower altitudes (up to 1250–1800 m), while in summer the distribution is concentrated almost exclusively above 2100–2300 m, with upper limits reaching and exceeding 3000 m. In autumn, there is generally a reduction in the number of contacts and a partial descent in altitude.

From the point of view of the monitored territories, there is a marked loyalty to the south-western sector of the Park, in the Champorcher Valley, which represents the area with the highest presence of the species in all seasons and in all the years analysed. The sectors of Fénis and Champdepraz seem to be used secondarily and mainly in summer, while the rest of the park territory seems to show sporadic or absent presence, probably linked to the sampling effort.

The distribution observed suggests a preferential selection for rocky environments, high-altitude grasslands and peripheral or marginal areas of the park, characterised by high isolation and reduced accessibility. A strongly recurring element of the analysis is the possible inverse correlation between the presence of ibex and the intensity of human activity. In all the years and seasons monitored, almost all observations are located:

- in areas far from the official trail network
- near trails with no or very low traffic
- in areas with no usage data or not affected by the main tourist flows

There are no reports near trails with medium, high or very high traffic, even during the summer, when the number of observations increases. This evidence could indicate sensitivity to anthropogenic disturbance, which in the summer season translates into a shift to higher altitudes in relation to seasonal climatic conditions and increased anthropogenic pressure.

The data analysed indicate that ibex within the Mont Avic Natural Park adopt a highly selective spatial strategy, based on:

- priority use of high-altitude environments
- loyalty to specific areas with high isolation (in particular south-western Champorcher)
- little interaction with areas subject to greater anthropogenic disturbance

Black grouse* *Lyrurus tetrix

The graph showing observations of *Lyrurus tetrix* highlights marked seasonal and interannual variability (Figure 2.11). Spring observations are clearly predominant between 2019 and 2022, with values ranging from 40 to 46 contacts, followed by a sharp decline in 2023 and a slower decline in 2024. In the remaining seasons, partly opposite trends are observed: between 2019 and 2020, values remain low (≤ 11 contacts), with stability in summer and increases in winter and autumn. In 2021, there is a reduction in sightings in winter and autumn and a slight increase in summer. In 2022, autumn observations still show a slight decline compared to previous years, while there is a marked increase in summer and winter. In 2023, there is a significant increase in contacts in winter and autumn, which is more moderate in summer. Finally, in 2024, there is a general decrease in observations in all seasons considered.

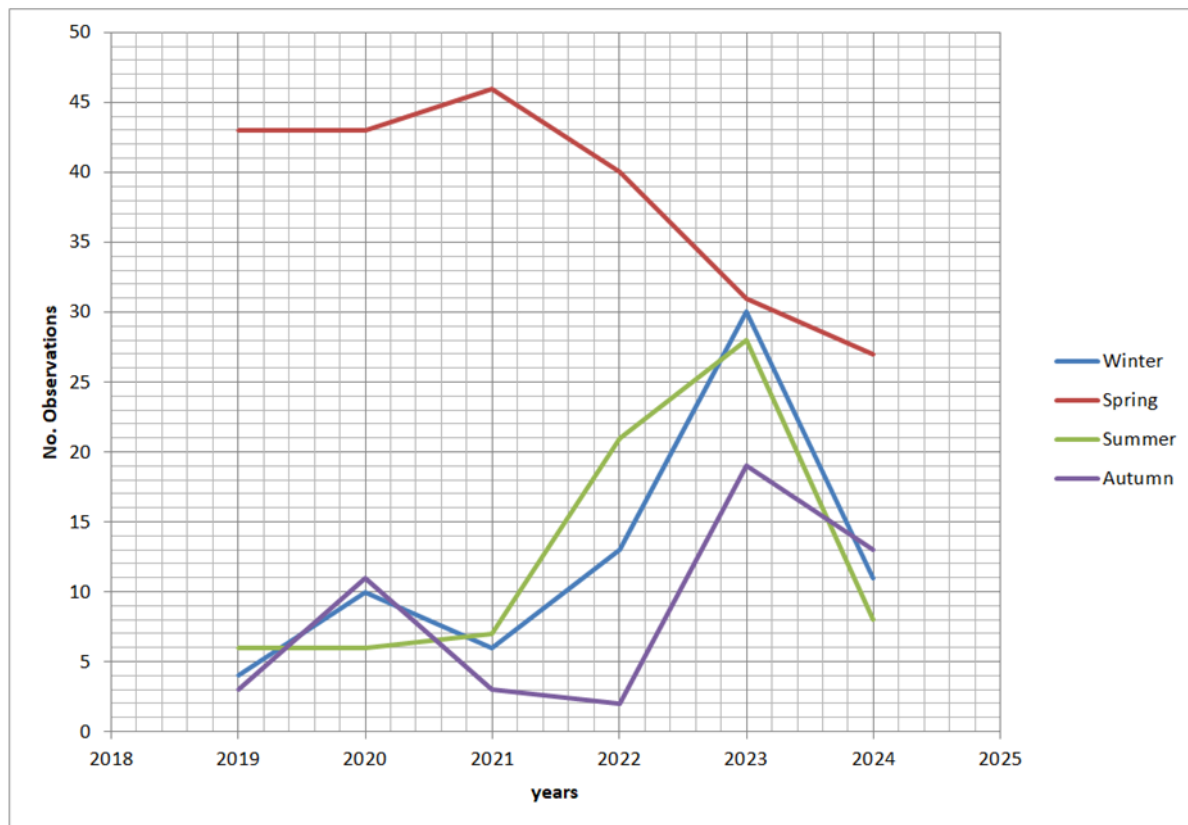


Figure 2.11 Seasonal distribution of Black grouse observations in 2019–2024 period.

Throughout the period analysed (2019-2024), the black grouse shows a marked peak in observations in spring, consistent with the breeding season and singing activity. Observations are generally high even in winter for several years, while they decrease significantly in summer and reach their lowest values in autumn.

The altitude range occupied by the species is relatively stable and typical of forest environments and the upper forest limit, mainly between 1600 and 2200 m. In summer, a descent to lower altitudes (up to 1250 m) is sometimes observed, probably linked to the use of cooler and more covered forest habitats, while in autumn the average altitude tends to increase slightly.

The spatial distribution of observations shows a strong dependence on forest cover, with a clear preference for the densely wooded areas of the Park. In all the years analysed, the north-eastern and eastern sectors of Champdepraz emerge as the areas with the greatest stability and continuity of sightings of the species, making them its main habitat.

The Champorcher sector is used more discontinuously and mainly in the south-eastern and eastern parts, while the Fénis sector is frequented more sporadically, especially in summer.

The multi-year analysis seems to show a predominantly inverse relationship between the presence of the species and the intensity of human activity, partly because most of the forest environments are crossed by paths with very low average usage data. Most of the observations are located:

- in wooded areas crossed by few paths
- near trails with no or very low use
- in areas with no usage data

Sporadic sightings have been reported near trails with medium to high traffic, especially in spring and, in some years, in winter. However, during the summer – coinciding with peak tourist season – observations show that the species is almost never encountered near the most popular trails, concentrating exclusively in areas with less human pressure.

Observation data indicate that the black grouse is mainly concentrated in the park area, which is rich in suitable forest habitats and where anthropogenic disturbance is partially avoided, particularly evident during periods of peak tourist traffic.

Rock ptarmigan* *Lagopus muta

The graph of *Lagopus muta* observations for the period 2019–2024 shows a low overall frequency of contacts (≤ 10 per season) and marked seasonal and interannual variability (Figure 2.12). Summer generally represents the season with the highest average number of observations, while the absolute peaks are recorded in spring in 2022 and 2024. Between 2019 and 2020, there were no contacts in winter, a reduction in spring and autumn (down to zero observations in 2020) and an increase in summer. In 2021, there are no observations in autumn, with slight increases of one unit in winter and spring and a decrease in summer. In 2022, there is a marked increase in spring and an increase in summer and autumn, compared to no contacts in winter. In 2023, the data are stable in autumn and summer, increasing in winter and zero in spring. Finally, in 2024, there are no observations in winter, a further increase in autumn, a decrease in summer and the highest spring value of the entire study period.

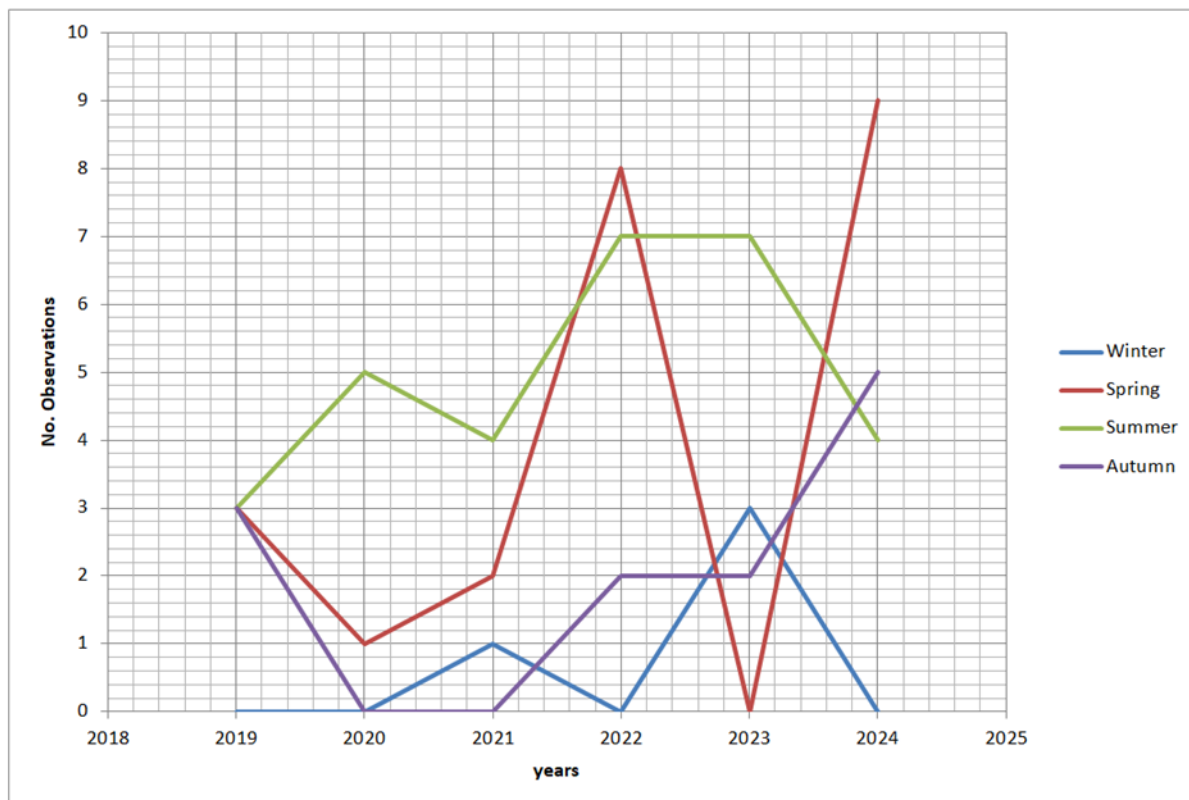


Figure 2.12 Seasonal distribution of Alpine ibex observations in 2019–2024 period.

Analysis of data collected between 2019 and 2024 confirms that the rock ptarmigan (*Lagopus muta*) maintains a constant, even if numerically limited, presence within the park. The number of seasonal observations generally varies between 2 and 9 individuals. The highest number of sightings was recorded in the spring of 2022 (8) and in the spring of 2024 (9). There is a drastic reduction or absence of data during the winter seasons, with the exception of 2023 (3 observations).

The species is confirmed as a high-altitude indicator, with a range that almost always stabilises above 2300 m. The maximum record was reached in 2021 with an observation at 3050 m. In summer and autumn, there is a tendency to climb to higher altitudes (up to 2900-3000 m), probably to escape the rising temperatures and seek more suitable habitats. The only significant exception occurred in 2021 and 2020, with sightings at 1700 m in summer, data potentially linked to contingent factors during the pandemic period.

A determining factor in the distribution of the rock ptarmigan seems to be human presence. The historical series analysed highlights a survival strategy based on the systematic avoidance of disturbance. In summer, coinciding with the increase in tourism, the species tends to move

towards the western sectors (Champorcher) or remote areas not served by the main trail network. In autumn, there is a further shift towards the south-western sectors, areas characterised by almost complete tranquillity. All observations take place in areas where human traffic is non-existent or very low, confirming the species' tendency to use habitats and environments in the park that correspond to areas where outdoor activities are less concentrated.

Although the data available for this analysis are limited in number, it is nevertheless clear that the observations describe the presence of the species, which is rarely observed even where levels of tourist disturbance are moderate. The presence of areas with low anthropogenic impact, corresponding to the western and south-western sectors, is fundamental for the persistence of the species in the park, and the trail network appears to act as a barrier or exclusion factor. The distribution of the rock ptarmigan changes according to seasonal human flows. Despite the low number of sightings and the high specificity of the habitat, the protection of less frequented high- altitude valleys must be considered in the management of the Park.

2.1.2 Impacts on habitat

2.1.2.1 Introduction

As part of this study, a specific line of analysis was dedicated to assessing habitat fragmentation phenomena induced by anthropogenic pressure along the official trail network of the Mont Avic Natural Park. In particular, attention was focused on the effects of repeated trampling associated with hiking, which is one of the main factors of physical disturbance to the soil and vegetation cover in alpine environments.

The concentrated transit of a large number of visitors along linear routes causes significant alterations to the physical, chemical and biological characteristics of the soil, as well as structural changes to the vegetation. These processes can contribute to the degradation of habitats and, in the medium to long term, to their functional and spatial fragmentation.

Extensive scientific literature has documented the effects of trampling on mountain ecological systems, highlighting how alpine and subalpine ecosystems are characterised by reduced resilience to mechanical disturbances. Experimental studies show that trampling intensity of approximately 700 passes can result in a reduction in vegetation height of between two and four times compared to natural conditions, while a 50% loss of vegetation cover can occur after just 440–450 passes, with persistent effects even one year after the disturbance (Aber et al., 2019).

The reduction in vegetation cover compromises the growth and reproduction processes of plant species, while promoting surface runoff, soil erosion and slope instability. Soil compaction, a key pedological phenomenon associated with the presence of trails, is greatest along the route and in the immediately adjacent areas, leading to a decrease in porosity, water infiltration capacity, oxygenation and root development. Hiking trails are therefore areas with high susceptibility to erosion, both due to the linear erosion of the trail and the concentration of water runoff and the triggering of slope destabilisation processes (Ballantyne & Pickering, 2015; Leung & Marion, 1996).

2.1.2.2 Materials and Methods

For the purposes of this analysis, the methodological approach was inspired by the analysis carried out in Berchtesgaden National Park (Germany), which focused on the ecological impact of the creation of unofficial trails and visitor management strategies. This case study analysed the conflict between nature conservation and recreational use in National Parks (IUCN category II).

The German study highlighted how the spontaneous formation of unplanned trails, generated by trampling outside official paths, causes soil compaction, erosion and vegetation degradation, with potential repercussions on the entire ecosystem balance. Berchtesgaden National Park was selected as the reference area due to the high tourist pressure (approximately 1.6 million visitors per year) and the management interest in containing the dispersion of hiking flows.

In the context of the Mont Avic Natural Park, it was not possible to achieve a level of detail similar to that of the Berchtesgaden study, due to the different data already available and the time limitations dictated by the project, constraints also due to the unavailability of spatial information such as the Digital Elevation Model (DEM) and CIR orthophoto maps useful for defining the Normalised Difference Vegetation Index (NDVI). However, the adoption of an approach based on multi-temporal photo interpretation of historical orthophoto series of the Mont Avic protected area has provided significant insights into the evolution of habitat fragmentation along the trail network.

In a preliminary phase, thanks to the support of Park staff who know the area and its dynamics very well, two sections of trail were identified and selected that showed clear signs of degradation due to trampling, such as the widening of the official route and the formation of unauthorised alternative paths.

The trails selected for analysis were:

1. Trail no. 8b in the Champorcher valley
2. Trail no. 10 in the Champorcher valley

The analysis was conducted by comparing different series of orthophotos acquired at different times, used as a basis for photo interpretation in a GIS environment (QGIS). The orthophotos used were as follows:

- 1998–1999 orthophotos: Terraltaly IT2000 digital colour orthophotos (nominal scale 1:10,000, ground resolution 1 m)
- 2005–2006 orthophotos: AGEA thematic orthophotos, mosaicked in ECW quadrants (reference cut 1:5,000)
- 2012 orthophotos: cartographic orthophotos with a ground resolution of 20 cm, UTM 32N – WGS84 reference system (EPSG: 32632)
- 2018 orthophotos: AGEA thematic orthophotos (reference scale 1:5,000)
- 2021 orthophotos: AGEA thematic orthophotos (reference scale 1:5,000)

The 1998–1999 edition was taken as the initial time reference ('zero point'), as it was considered to have no detectable fragmentation effects.

The orthophotos made it possible to identify sections of the trail that had been affected over the years by widening and the appearance of new unofficial tracks. These areas were digitised in a GIS environment by creating polygons associated with dedicated shapefiles, each catalogued by reference year. The area affected by trampling was calculated for each polygon. A comparison of the areas surveyed in different years allowed for an initial quantification of the spatial evolution of the disturbed areas and a preliminary assessment of the intensity of habitat fragmentation.

2.1.2.3 Results

Trail no. 8b

Trail no. 8b runs through the Champorcher valley from the fork in trail A2 (2,330 m above sea level) to Col Moutsaillon (2,854 m above sea level). The section under analysis extends between 2,370 m and 2,450 m, for a linear length of approximately 518 m.

The analysis showed a gradual increase in the areas affected by trampling and the formation of alternative tracks, often aimed at shortening the route by avoiding hairpin bends. The total

area of disturbed areas increased from 59.15 m² (2005–2006 orthophoto) to 436.05 m² (2021 orthophoto), with a particularly marked increase in the last series analysed (Table 2.6; Figure 2.13).

- For the 2005/2006 series, there are three new sections along the official trail compared to the 1998/1999 map, with a total area of 59.15 m²
- For the 2012 series, seven new sections were recorded compared to the 1998/1999 map, covering a total area of 94.36 m²
- For the 2018 series, eight new sections were identified compared to those shown on the 1998/1999 map, covering a total area of 104.56 m²
- For the 2021 series, ten new sections were identified compared to the 1998/1999 map, covering a total area of 436.05 m²

Orthophoto	Path	No. Unofficial sections	Area m ²	Increase m ²	Increase %
2005/2006	8	3	59.15	0	0
2012	8b	7	94.36	35.21	59.53
2018	8b	8	104.56	10.2	10.81
2021	8b	10	436.05	331.49	317.03

Table 2.6 Paths 8 and 8b: the informal trails evolution from 2005 to 2021



Figure 2.13 Section of trail 8b where informal sections are visible – 2012 orthophoto series

Although visitor data collected by surveillance personnel between 2019 and 2024 indicate generally low use of the trail, cartographic evidence suggests that the causes of this phenomenon need to be investigated further, as they may include factors other than hiking, such as the transit of livestock during the mountain grazing season.

Trail no. 10

Trail no. 10 also runs through the Champorcher valley, starting at an altitude of 1,770 m near the village of Petit Mont Blanc, and leads to Lac Muffé, the refuge of the same name and then to Col du Lac Blanc (2,309 m above sea level). The section analysed extends between 1,910 m and 2,120 m, with a linear length of approximately 918 m.

A comparison of the orthophotographic series showed a significant increase in the areas trampled, with a peak recorded in the 2012 orthophoto (636.38 m²) and a subsequent partial reduction in the 2018 and 2021 series. However, the total disturbed area is still significantly higher than the initial values for 2005–2006 (143.7 m²).

The situation is clearly illustrated by the images below, which compare a section of trail 10 just upstream of Lac Muffé. The first image shows the route captured in the 2005/2006 orthophoto, while the following image, taken from the 2012 orthophoto, clearly shows the new trail that runs to the left of the official trail.

The comparison of the orthophotos has highlighted the following:

- For the 2005/2006 series, there are seven new unofficial sections compared to those shown on the 1998/1999 map, with a total area of 143.7 m²;
- For the 2012 series, 12 new sections were recorded compared to the 1998/1999 map, covering a total area of 636.38 m².
- For the 2018 series, eight new sections were identified compared to the 1998/1999 map, covering a total area of 550.16 m².
- For the 2021 series, there are again eight new sections highlighted compared to the 1998/1999 map, covering a total area of 598.44 m².

The analysis carried out does not allow us to determine whether the reduction recorded between the 2012 series and subsequent series (-13.55%) is actually linked to a reduction in users' habits of travelling on unofficial routes or whether the difference is linked to objective errors resulting from photo interpretation.



Figure 2.14 The image above refers to 2005/2006 Orthophoto and the one below to 2012 Orthophoto

Orthophoto	Path	No. Unofficial sections	Area m ²	Increase m ²	Increase %
2005/2006	10	7	143.7	0	0
2012	10	12	636.38	492.68	342.85
2018	10	8	550.16	-86.22	-13.55
2021	10	8	598.44	48.28	8.78

Table 2.7 Paths 10: the informal trails evolution from 2005 to 2021

In the case of trail no. 10, the high level of human traffic is consistent with the usage data collected by Park staff in the period 2019–2024, which indicate high or very high numbers of visitors, particularly during the summer season. The reduction observed between some time series could be attributable to both behavioural changes among users and intrinsic limitations of photo interpretation.

2.1.2.4 Discussion

This analysis of habitat fragmentation has provided initial indications of how human pressure associated with the use of the Mont Avic Natural Park trail network represents a significant disturbance factor for alpine ecosystems, particularly through intensive trampling. The repeated passage of visitors along the trails causes physical alterations to the soil and vegetation cover, promoting compaction, erosion and loss of habitat continuity.

Analysis of sections of trails 8b and 10 found a significant increase in trampled areas during the period analysed. This situation for trail 10 appears to be clearly attributable to the high number of hikers, which grew steadily during the period analysed. For trail no. 8b, which, according to the data collected so far, is characterised by generally low levels of use, the

increase in disturbed areas suggests the need for targeted and detailed investigations in order to better explain the causes, which could also include the influence of additional factors, such as the transit of livestock during the mountain grazing season. In the case of trail no. 10, one of the most frequented in the Park, the increase in fragmentation is consistent with high anthropogenic pressure, especially in the summer.

Overall, the preliminary results of the analysis show that habitat fragmentation caused by trampling is also present within the Mont Avic Natural Park, although the intensity and causes need to be investigated further. This evidence highlights the importance of integrating visitor monitoring with more in-depth and systematic analyses, supplemented by more detailed surveys – as already done in similar studies – in order to carry out a more accurate and functional analysis for monitoring the evolution of the phenomenon. This is both to support the possible adoption of new management and mitigation measures with scientific evidence and to make them as consistent as possible with the conservation objectives of the Park.

2.2 Case study 2: Habitat loss in Berchtesgaden National Park

The second case study concerns the ecological impact of the creation of unofficial trails and appropriate visitor management measures. The work was carried out as part of Charlotte Sophie Ritter's Bachelor of Arts thesis in Geography (2024), entitled *Fußabdruck des Wanderns: Eine GIS-basierte Erfassung informeller Wanderpfade im Nationalpark Berchtesgaden sowie ihrer ökologischen Sensibilität zur Identifizierung angepasster Naturschutzmaßnahmen* (Footprint of hiking: A GIS-based survey of informal hiking trails in Berchtesgaden National Park and their ecological sensitivity for the identification of adapted nature conservation measures).

The central theme of the research is the conflict between nature conservation and recreational use in National Parks (IUCN Category II), in particular hiking, which is the most popular form of recreational use on the one hand and a serious ecological threat on the other. Informal trails, created by trampling outside official paths, are not planned in line with conservation objectives and cause soil compaction, erosion and vegetation disturbance, which can destabilise the entire ecosystem. Berchtesgaden National Park, the only high-altitude alpine national park in Germany, was chosen as a case study due to the high tourist pressure (approximately 1.6 million visitors per year) and the interest of its administration in managing the growing problem of visitors leaving the main trails.

The analysis of the phenomenon involved two main phases:

1. Mapping of informal trails using a Geographic Information System (GIS - QGIS) to manually digitise informal trails on aerial images of four selected study areas (chosen based on prior knowledge of the problem and visibility) for the years 2009, 2015 and 2020.
2. Classification of Ecological Sensitivity by analysing the ecological sensitivity of the affected areas, based on the three most important parameters: slope, habitat types (LRT) and soil erodibility.

The results showed that a positive trend was observed from 2009 to 2020: the total area of informal trails decreased in all study areas. Despite the reduction in overall area, the Normalised Difference Vegetation Index (NDVI), which indicates the state of vegetation, showed that the informal trails that still exist cause serious damage to vegetation. On average, the NDVI within informal trails was consistently lower than in the surrounding environment in all the years analysed: this indicates that vegetation cover has been damaged or completely lost due to trampling.

With regard to ecological sensitivity, the areas at greatest ecological risk were identified. To this end, a classification of ecological sensitivity based on three main parameters was implemented, inspired by the general model of environmental sensitivity: Topographical Factor - Inclination (Slope); Ecological Factor - Habitat Types (Biotopes); Pedological Factor - Soil Erodibility. Three out of four study areas were found to be particularly sensitive from an ecological point of view, combining valuable and vulnerable habitats with erodible soils and steep slopes, which gives informal trails a particularly high potential for damage. The other study area, on the other hand, showed lower overall ecological sensitivity but has the highest density of informal trails. The detailed analysis identified area-specific measures tailored to the causes of informal trail formation and their ecological sensitivity in order to protect sensitive ecosystems and improve the visitor experience and safety.

Several types of measures are proposed. For highly sensitive areas where trails cannot be accepted, the physical closure of informal paths is recommended; the use of low symbolic fences, such as posts and rope fences, is suggested, as these have been found to be more effective than signs alone in preventing people from leaving the main path. Re-naturalisation efforts are essential, including soil loosening, organic fertilisation and active planting of native species, which are crucial but only effective if the area is fully and permanently protected. As preventive measures, it is recommended to widen the main paths, improve the quality of the surface and mark their sides (e.g. with a row of stones) to prevent the creation of paths parallel

to the main route (e.g. to overtake other hikers). Educational measures aimed at changing visitor behaviour are also recommended, although they are less effective than direct management measures.

Following this thesis, no *ad hoc* 'monitoring project' has been launched. The Park is keeping an eye on the phenomenon and is evaluating what to do with the Planning and Science departments; unfortunately, the budget cuts that the protected area is undergoing do not allow for the launch of dedicated projects (Ulf Dworschak, personal communication).

2.3 Case study 3: Swiss National Park

The third case study is represented by the work of Anderwald et al. (2021). The study analysed the physiological responses to stress of two sympatric ungulate species in the Swiss Alps: the Alpine chamois (*Rupicapra rupicapra*), a typical mountain ungulate, and the red deer (*Cervus elaphus*), originally adapted to open plains. The aim of the study was to verify whether these species, which have different ecological adaptations (habitat and diet), differed in their responses to stress from three potential factors: weather conditions (humidity, temperature, snow depth), forage quality and human disturbance (number of visitors). The study was conducted in the Swiss National Park, a strictly protected area where hunting is prohibited and disturbance is minimal (access to the park is prohibited during the winter season).

Stress responses were quantified by measuring concentrations of faecal glucocorticoid metabolites (FGM), a physiological indicator of stress, in non-invasive faecal samples (742 from chamois and 1,557 from red deer) collected every two weeks for four years (2015-2018). Only the results relating to the human disturbance factor are reported. The initial hypothesis was that the authors expected a stronger response to human disturbance from red deer than from chamois, as chamois are more agile and able to quickly take refuge on rocky outcrops (escape terrain) present in the study area. The results showed no response to stress in either species in relation to changes in visitor numbers during the hiking season (June-October).

As outlined in the Focus Group discussion (see Section III), the interview with the Swiss National Park expert highlighted the park rules that stipulate the only outdoor activity permitted in the protected area is hiking, which must take place on official trails from which it is not possible to stray. These trails allow visitors to admire wildlife, particularly deer, from a distance that does not disturb them. All other activities, such as snowshoeing, ski touring, cycling, etc., are prohibited, as is the entry of dogs, even on a leash. During the winter, it is forbidden to enter the Park.

2.4 Case study 4: Ossola Protected Areas

The fourth case study concerns the black grouse and the mountain hare in the Veglia-Devero Natural Park (North-Western Italian Alps).

Black grouse *Lyrurus tetrix*

For this species, the relationship with human presence has been investigated in two different studies by Formenti et al. (2015) and by Bionda et al. (2019). According to Formenti et al. (2015), populations of the black grouse have declined dramatically in recent decades, particularly since the 1970s, and are considered endangered or extinct in many areas. In Italy, the intensification of winter sports poses a growing threat to this species, as it can impact individual fitness by frightening and driving away animals, especially in winter when energy requirements are higher and food resources are limited. Winter sports infrastructure is often installed close to suitable black grouse habitat, causing degradation and fragmentation. Ski tourers, snowboarders and snowshoers can cause an increase in circulating glucocorticoids in birds by accidentally chasing them from their snow burrows (igloos).

The analyses were conducted in three macro-areas with different levels of human disturbance:

1. High disturbance: characterised by a ski area with 2.042 kilometres of ski lifts, ski slopes and trails for freestyle skiing, ski touring and snowshoeing; black grouse must dig their igloos close (less than 100-200 m) to the ski area or between the ski lifts;
2. Moderate disturbance: close to a highly disturbed area characterised by ski touring trails; the distance between the black grouse burrows and the ski resort is approximately 500 m;
3. Low Disturbance: distant and isolated, but accessible to some ski mountaineers and snowshoers. Here, the animals dig igloos at a distance of more than 500 metres from sources of stress.

In order to assess the physiological response to stress using a non-invasive method, faecal corticosterone metabolites (FCM) were quantified in 58 droppings collected near the same number of igloos in the snow in the winters of 2010/2011 and 2011/2012.

The two sampling periods differed in terms of snow cover:

- 2010/2011: High snow cover with regular and abundant snowfall from late October to spring
- 2011/2012: Low snow cover with little snowfall in January and February, with snow melting rapidly in March due to rising temperatures and strong winds

Studies have found that FCM concentrations were significantly influenced by area and snow cover. In winters with high snow cover, FCM values in the high disturbance area were significantly higher than those in the moderate disturbance areas. In winters with low snow cover, no differences in FCM values were found between the three areas. Based on the results, the authors point out that the interaction between high snow cover and high disturbance from winter sports led to the highest FCM concentrations, indicating a stressful condition for black grouse. The regular presence of tourists could negatively affect the survival of birds that dig igloos near the facilities. In areas with moderate and low disturbance, hormone levels were significantly lower, reflecting less regular or sporadic public access. In addition, greater distance (approximately 500 metres or more) between black grouse habitat and visitor routes/infrastructure contributes to less anthropogenic disturbance. During the winter with low snow cover, the lack of snow led to a drastic reduction in sporting activities and public access. This made human disturbance levels uniform for animals in all three areas, showing no significant differences in FCM levels. However, in the winter with low snow cover, FCM values in areas with moderate and low disturbance were higher than in the winter with high snow cover. This suggests that the unusual climatic conditions and lack of snow (which is important for the black grouse's winter roosting strategy) imposed an additional allostatic load, increasing stress hormone levels.

The results of this research indicate a relationship between increased stress hormone levels in black grouse and regular disturbance caused by winter sports. Given that induced stress can reduce disease resistance and contribute to population decline, human disturbance poses an additional serious threat. The authors hope that tourism management will be planned to support black grouse conservation and that the results will be considered in the planning of new infrastructure for snow sports.

The second study available is the report *Survey of the distribution of areas frequented by tourists in winter and wintering areas of the black grouse Lyrurus tetrix in a sector of the ZSC/ZPS IT1140016 'Alpi Veglia e Devero e Monte Giove'* with high human traffic by Bionda et al. (2019). The survey reports a doubling of visitor numbers in just over a decade: in the winter of 2018-19, Piazza (2019) estimates around 80,000 visitors to the Devero Alp area from December to March, double the number estimated in the winter of 2005-06 (Piazza, 2006). A significant percentage of these visitors frequent ski mountaineering and snowshoeing routes, or engage in off-piste skiing in the Monte Cazzola area, where there is a ski lift. In many cases, the areas frequented by tourists coincide with those suitable for some of the species that winter in the site. The aim of the survey carried out by the authors was to identify the areas frequented by black grouse in the Alpe Devero sectors most suitable for wintering and, at the

same time, affected by recreational activities such as off-piste skiing, ski mountaineering and snowshoeing, in order to identify the 'quiet areas'. Traces of recreational human activity were observed in 70.2% of the cells in which the area was subdivided, of which 76.5% were related to ski mountaineering, 14.3% to off-piste skiing, 4.4% to snowshoeing outside marked trails, 3.2% to snowshoeing on marked trails and <1% to hiking. The analysis also made it possible to define the high degree of overlap between the areas frequented by black grouse during the delicate wintering period and those affected by human presence, highlighting the potential impact that recreational activities can have on this species. Since the area under investigation is home to a large part of the population surveyed annually at Alpe Devero, it is likely that the disturbance caused by users of the area may have an effect on a significant proportion, if not the entirety, of the black grouse population present in the Alpe Devero basin.

Following the results of this study, it has been considered necessary to adopt measures to reduce the impact of human disturbance on this species by identifying 'quiet areas' as provided for in the site-specific conservation measures. These areas were identified as part of the RESICETS Project, taking into account the needs of two other species of conservation interest present in the study area: rock ptarmigan and mountain hare. RESICETS is linked to the Be Part of the Mountain initiative, coordinated by ALPARC. Be Part of the Mountain is an international cooperation project that aims to bring together protected areas, environmental NGOs, public bodies, alpine clubs and ambassadors throughout the Alps, focusing on a shared communication campaign to raise awareness among hikers and outdoor enthusiasts of the impact of human activity on the natural resources of Alpine protected areas, and to give greater visibility to local initiatives launched in individual territories. The main objective is to encourage virtuous behaviour among winter sports enthusiasts through the exchange of good practices, the development of common tools to raise awareness and the dissemination of information.

Aree Protette dell'Ossola and Coop. Devero 2.0 have signed an agreement identifying two 'highly protected' quiet areas in the Monte Cazzola - Vallone di Misano area, which are off-limits to skiers, snowshoers and hikers. Visitors can find out more before arriving on site via the dedicated pages of the Ossola Protected Areas website, or on site thanks to the information panels. It is interesting to note that the measures were agreed with the ski resort and that visitors to the area have accepted the restrictions willingly. Figure 2.15 shows an increment on the cells with reduced impact due to the visitors since the establishment of the quiet zones.

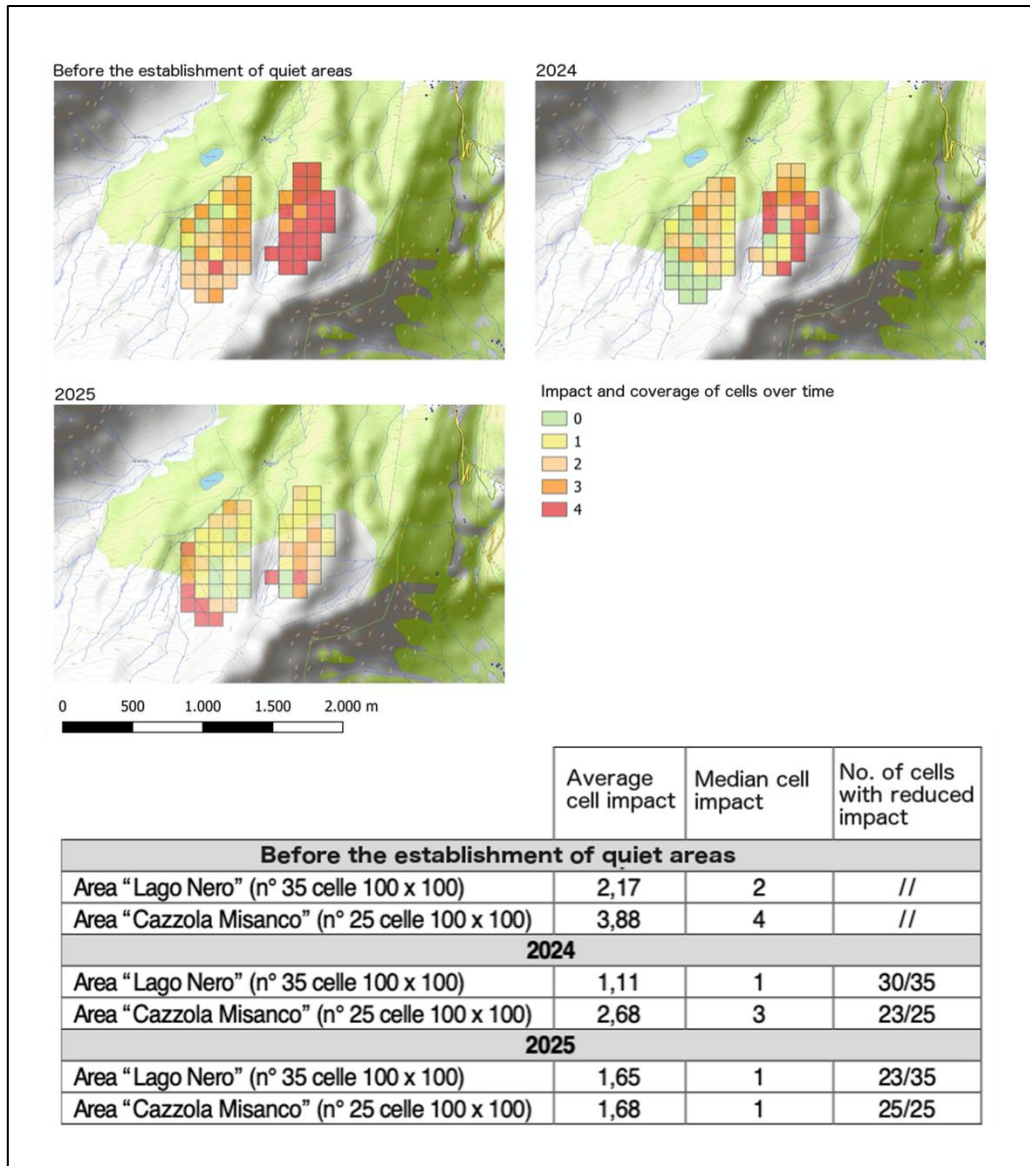


Figure 2.15 : Trend in the impact caused by visitors before and after the establishment of buffer zones

Although Figure 2.16 indicates an increase in the black grouse population in one of the areas affected by quiet zones, it is still too early to understand whether the establishment of quiet zones has had a positive effect or not. This increment, in fact, may be due to other variables that are part of population dynamics. It is necessary to proceed with the project in order to obtain a significant amount of data and be able to draw reliable conclusions.



Figure 2.16 Trend in the population of black grouse in the Cazzola-Lago Nero area.

Mountain hare *Lepus timidus*

The results of a study on the mountain hare are also reported, as highlighted in the report *Survey on the distribution of the mountain hare Lepus timidus varronis in some sample areas in the ZSC/ZPS IT1140016 Alpi Veglia e Devero – Monte Giove* (Bionda et al., 2020).

The survey, carried out in the summer of 2019, aimed to collect information on the spatial distribution of the species in some sample areas of the Natura 2000 site Alpi Veglia e Devero – Monte Giove, in order to identify areas with sufficient density to apply ad hoc monitoring techniques (Fecal Pellet Count, Camera Trap) and to collect information on the species' habitat use. The data collected made it possible to verify that low levels of anthropogenic disturbance correspond to a higher probability of finding hare faecal pellets, whose contactability decreases as the level of disturbance increases.

With a view to zoning measures aimed at limiting winter use in order to protect species of conservation interest, it should be borne in mind that lower tourist pressure in winter could have a positive impact on the distribution of the species.

2.5 Case study 5: Karkonosze National Park

The final case study examined is the work of Rusztecka-Rodziewicz et al. (2025, unpublished data), which analysed anthropogenic pressure in the Karkonosze National Park through a multimodal data collection approach.

Located on the border between Poland and the Czech Republic, Karkonosze National Park was established to protect the highest peaks of the Sudetes range. Although this study does not directly concern the Alpine region, the area presents significant analogies with the habitats and challenges of the Alpine parks analysed in this report. The Park's morphology was heavily shaped by Pleistocene glaciers, and it still hosts a wide array of biodiversity and numerous glacial relict species. Karkonosze National Park is a major tourist destination, attracting approximately 2.5 million visitors annually. This high level of foot traffic poses a threat to environmental preservation and represents a central challenge for the management of the protected area.

The objective of the study is to analyse anthropogenic pressure by identifying the most vulnerable areas, visitor distribution patterns, and peak hours. Concurrently, spatial distribution patterns of fauna were mapped to identify areas of high criticality and potential conflict. The data were collected by integrating multiple sources:

- Statistics from automatic counting systems (eco-counters) installed in 18 locations
- Data from entry fees
- Camera trap recordings
- Data from hiking application (STRAVA)

Flow analysis using eco-counters identified peak areas and times (Figure 2.17). In particular, the data highlighted that during high season, human presence is constant throughout the day and, in some hot spots, e.g., the Śnieżka peak, extends into the nighttime, thereby increasing overall disturbance to wildlife. However, during breeding season, there is social acceptance of restrictions on tourism, such as closing selected tourist trails. The use of STRAVA data enabled the creation of detailed cartography of the most frequented trails and the types of sporting activities practiced (trekking, cycling, trail running, etc.). Simultaneously, monitoring of fauna and human presence was conducted via camera trapping, with 135 locations off the official trail network and 60 stations directly on trails. The collected images were processed using a specialized artificial intelligence application⁹ trained to automatically recognize 14 animal

⁹ Trapper AI <https://gitlab.com/trapper-project/trapper-ai>

species, as well as humans and vehicles (Figure 2.18). The following information was extracted from the resulting database:

- Location and temporal data of observations expressed by the Trap Rate index
- Classification of subjects (identification of 14 wildlife species or type of human activity, such as motocross, walking with dogs, etc.)

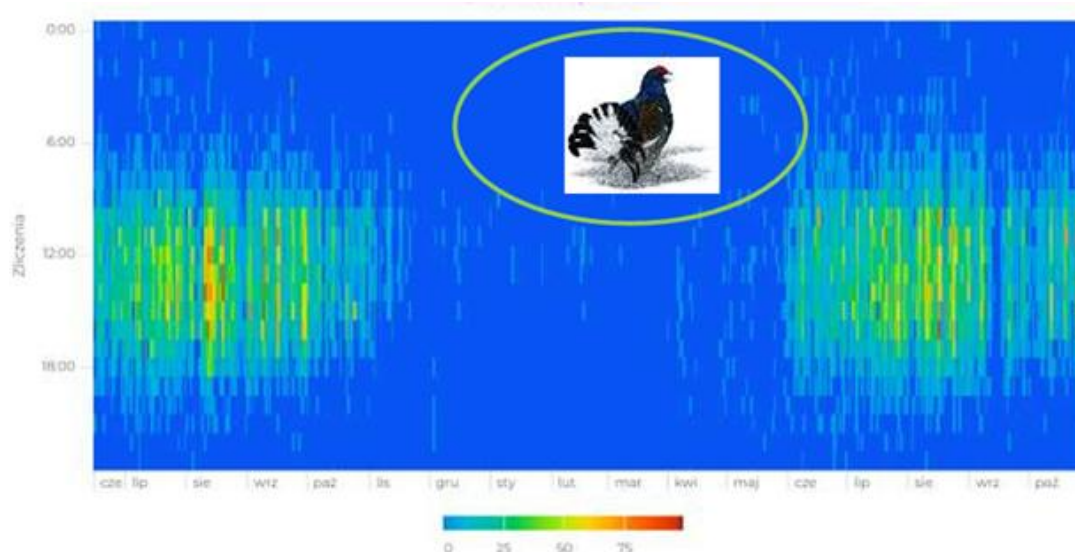


Figure 2.17 Heat map of the daily distribution and occurrence of visitors on Black Grouse habitats.

The spatial distribution of the trap rate indicator for animal species and for human and vehicle presence enabled the selection of hot spots and conflict areas. Combining camera-trap data and flows detected via STRAVA enabled mapping areas with the highest potential for conflict between anthropogenic activities and wildlife, and identifying sectors characterized by extremely high visitor density.

The results, based on integrating multiple sources for monitoring anthropogenic disturbance, provide a robust, multidimensional dataset. This knowledge base is fundamental for supporting management decisions, allowing for the precise identification of areas of high conservation interest and those most vulnerable to tourist pressure. Ultimately, the described methodological approach serves as an effective management tool, balancing tourism enjoyment with the Park's long-term conservation needs.

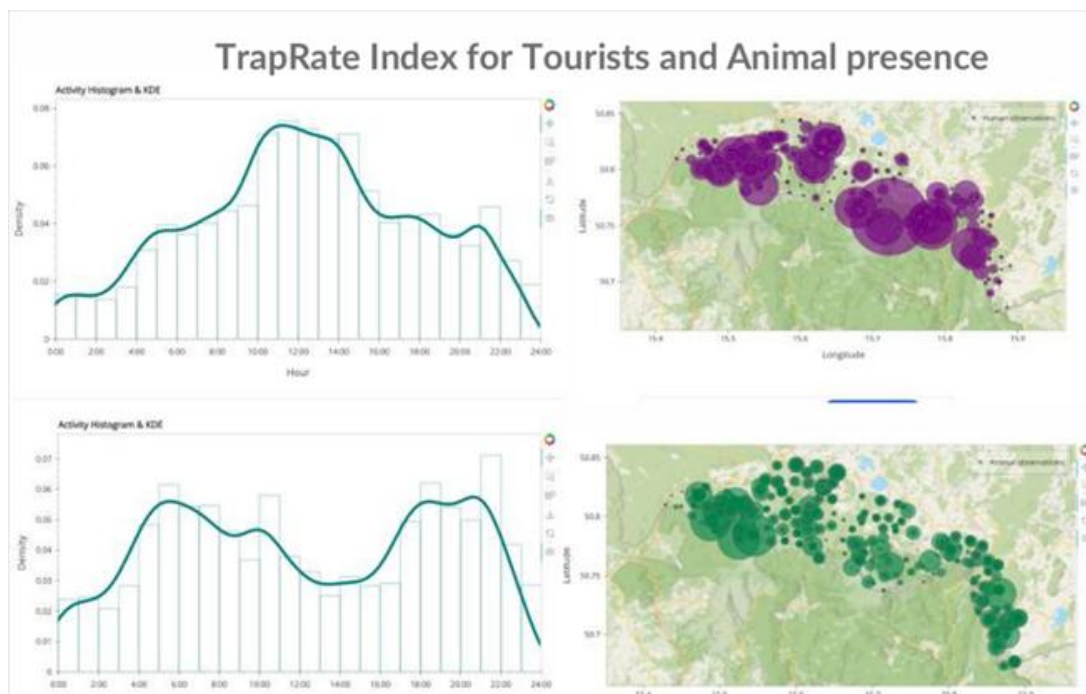


Figure 2.18 Daily activity patterns of tourists (top) and wildlife (bottom) within the park area, based on camera trap detection rates.

2.6 Conclusions

All the studies examined highlight that the disturbance caused by NBAs practiced in the protected areas investigated on wildlife and habitats is real.

In the Mont Avic Natural Park, both for chamois and ibex, an inverse correlation can be observed between the presence of the species and the intensity of use of the trails. Sightings are concentrated in areas far from the official trail network or along very little-used paths; this could indicate that disturbance caused by high frequency on trails causes animals to stay away from them. Black grouse and rock ptarmigan also seem to almost systematically avoid the busiest trails during peak summer tourist season, concentrating exclusively in areas with less human pressure.

With regard to ungulates, the situation is different in the Swiss National Park, where chamois and red deer are not disturbed by human presence. This difference is almost certainly due to the different quantity and use of trails. The Swiss trail network allows visitors to spot animals, but 'forces' them to keep their distance from the areas frequented by animals so as not to disturb them. In the Mont Avic Nature Park, the network of trails is very extensive and

widespread, so although the regulations stipulate that hikers must always stay on the official trails, it cannot be ruled out that they may cross areas frequented by the target species, causing disturbance. Another substantial difference between the two protected areas is winter accessibility: in the Swiss National Park it is prohibited, while in the Mont Avic Natural Park it is permitted, with restrictions on certain activities, such as ski touring, which is only allowed in certain areas.

With regard to the two species of tetraonids, studies carried out in the Ossola Protected Areas have shown that the combination of high snow cover and a high degree of human presence causes significant disturbance to the black grouse. The same studies have shown that there is a significant overlap between the off-piste areas used by skiers and those where black grouse are present. This situation has prompted the protected area to identify quiet zones, which correspond to those most used by black grouse, within which human presence is prohibited. The closure of certain areas was agreed with the ski resort management and was widely accepted by users. In the two years following the creation of the quiet zones, there was a marked decrease in the number of cells “disturbed” by human presence. At the same time, there was also an increase in the black grouse population in at least one of the study areas. However, considering that many variables influence population dynamics, it is still too early to say with certainty that the increase in population is linked to the establishment of quiet areas. It is hoped that, by continuing monitoring, useful data can be obtained to define a protocol that will lead to a reduction in human pressure on areas where black grouse are present.

The study conducted in the Karkonosze National Park highlighted that human disturbance is often concentrated in areas of high conservation priority. Furthermore, it underscored a pressing issue: the distribution of anthropogenic disturbance throughout the entire day, with activity recorded during periods typically associated with wildlife activity, such as at night, dawn, and dusk. The heavy human presence in protected areas not only disturbs wildlife, but also habitats. Taking as an example some of the methods used in the Berchtesgaden National Park, it has also been demonstrated in the Mont Avic Natural Park that the creation of informal (illegal) trails leads to increased land use and habitat fragmentation. At present, at least in the Italian protected area, the phenomenon only affects a few trails, but constant and thorough monitoring of all trails, the closure of unofficial trails and the restoration of the pre-existing situation are necessary. These activities are carried out periodically by the Park Authority, through park rangers and forestry workers.

3 Nature-based activity in protected areas: compatibility and impact assessment

3.1 Compatibility of NBA with the protection status of natural sites

To discuss the compatibility of outdoor activities (and more generally of tourism) with the objectives and the legal status of protected areas, it is necessary to move from the basics. According to the International Union for Conservation of Nature (IUCN), a protected area is “A clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, *to achieve the long-term conservation of nature* with associated ecosystem services and cultural values” (Dudley, 2008, emphasis added). Among the several important aspects emerging from this short definition, the most relevant for the present work concern the core mission of protected areas which is, as already discussed (see Lavorel et al., 2020), biodiversity conservation. In other words, within these regions the protection of nature should always be the priority and any other human use should be subordinate. Consistently, the European Charter for Sustainable Tourism in Protected Areas promoted by EUROPARC states as its first principle “Giving priority to protection” (EUROPARC, 2021).

At the same time, protected areas can represent an important resource both for individuals and for local communities. On the one hand, they provide ecosystem services such as recreational, relaxing and health-beneficial environments. On the other hand, even in Alpine regions characterised by overall depopulation, spots of demographic increase and economic success broadly correspond to tourism resorts (Permanent Secretariat of the Alpine Convention, 2013). Given that two-thirds of Alpine protected areas are located above 1,000 meters in altitude (and the figure rises to nearly 90% when considering strongly protected areas) (ALPARC, 2025), the attraction exerted by these destinations thanks to their exceptional natural heritage can make a significant contribution to regional development.

The spectrum of existing protected areas reflects the interaction between the primary objective of nature conservation and their expected contribution to (sustainable) regional development. The IUCN identifies six categories (Table 3.1), ranging from strict nature reserves with the highest level of protection to areas in which the sustainable use of natural resources by humans is explicitly recognised as an aim of the area itself (Dudley, 2008).

IUCN Category	Definition
Category Ia – Strict Nature Reserve	Protected areas with a strict biodiversity protection focus for globally outstanding ecosystems, species or geodiversity features, and human visitation is strongly restricted
Category Ib – Wilderness Area	Usually, large unmodified or slightly modified areas, retaining their natural character and influence, without permanent or significant human habitation, protected and managed to preserve their natural condition
Category II – National Park	Large natural or near natural areas with the goal to protect large-scale ecological processes, plus the species and ecosystems characteristic of the area ; human visitation is allowed for recreational and cultural uses
Category III – Natural Monument or Feature	Generally, quite small and set up to protect a specific natural monument (e.g., a landform, a cave or other geological or culturally influenced feature) with high visitor value, managed similarly to category II
Category IV – Habitat/Species Management Area	Set up for the protection of particular species or habitats , which is reflected in management interventions and may be relatively small; sometimes a “stop-gap” measure (e.g., to secure stepping-stones, breeding sites, etc.); may be located in significantly modified and fragmented areas
Category V – Protected Landscape/ Seascape	A protected area where the interaction of people and nature over time has produced an area of distinct character with significant ecological, biological, cultural and scenic value, which is considered worth protecting (e.g., unique or traditional land-use patterns); potential for ecological restoration
Category VI – Protected Area with sustainable use of natural resources	Generally, large, protected areas that conserve ecosystems and habitats, together with associated cultural values and traditional natural resource management systems (“sustainable use” as a means to achieving nature conservation); no large-scale industrial harvest

Table 3.1 IUCN Categories of protected areas (adapted from ALPARC, 2023)

The situation in the Alps is made even more complex due to the varying systems across countries, that present different legislations, governance levels and responsibilities, management objectives and practices, but also official designations and the possibility that different types of protected areas coexist in the same location (ALPARC, 2023). Table 3.2 provides an overview of Alpine protected area types and their equivalent IUCN category.

Protected area type	IUCN Category	Alpine examples
Main protected area types		
National Parks	II/V	Triglav National Park Berchtesgaden National Park Ecrins National Park Swiss National Park
Nature reserves	IV	ASTERS - Conservatoire d'espaces naturels de Haute-Savoie
Regional nature parks	II/IV/V	Ossola Protected Areas Mont Avic Nature Park
Other areas with particular protections		
Wilderness areas / strictly protected reserves	I (Ia/Ib)	Swiss National Park
Landscape protection areas	IV/V	Ötscher – Dürrenstein Landschaftsschutzgebiet
Protected parts of a landscape	III	Scheibelalm Geschützter Landschaftsteil (Protected Landscape Section)
Special conservation areas / Natura 2000 sites or Emerald sites	IV or other	Triglav National Park
Natural monuments / natural areas	III/IV/V	Naravni spomenik Gorska skupina Martuljek (within Triglav National Park) Mont Blanc - site d'exception
Natural forest reserves / strict protection forests	I/IV	Réserve biologique intégrale du Vercors – la Garsälli/Zegerberg Waldreservat – Ib Réserve biologique dirigée d'Archiane - IV
Quiet zones / extraordinary protected areas	I, II, III, V	Wilderness Area Sulzbachtäler – Ib within Hohe Tauern National Park
International designations		
UNESCO Biosphere reserves	various	Triglav National Park
UNESCO Global Geopark reserves	various	Adamello-Brenta UNESCO Global Geopark
UNESCO World Natural Heritage sites	various	Swiss Alps Jungfrau-Aletsch
Ramsar sites	various	Škocjanske jame

Table 3.2 Types of Alpine protected areas (adapted from ALPARC, 2023). Protected areas participating in LiveAlpsNature are marked in italics.

As a consequence, both the type and intensity of NBAs deemed compatible with nature conservation, as well as the restrictions that apply to them, vary according to the protection status and the country of each protected area. Yet, if nature conservation is to remain the primary goal of every protected area, it should be possible, at least in principle, to identify a threshold of disturbance to biodiversity that applies globally and can be then adapted to the specific level of protection. This threshold of acceptable disturbance should be placed below the carrying capacity of the natural environment. Adapting the existing definitions (Long et al., 2022; UNWTO, 1983; Zekan et al., 2022) to NBA, the carrying capacity represents the maximum number of practitioners, or the maximum intensity of activities, that the environment can tolerate without compromising its ecological structures. In practice, park managers report that, while it might be possible to calculate the carrying capacity for very limited locations (such as a trail), extending it to large or spatially complex areas doesn't seem to be possible. The concept can however serve as a useful guideline or compass for assessing the impact of human activities.

Section II presented valuable methods to measure biodiversity disturbance. Several protected areas have implemented some form of visitor-counting tools, as visitor number is probably the most straightforward indicator of pressure on nature and among the easiest to define. Information on the spatial and temporal distribution of visitors allows for more effective management measures, especially when combined with data on the activities undertaken and the sensitivity of specific zones. Other indicators used by park authorities include erosion in the vicinity of paths and the emergence of new "unofficial" trails, changes in animal behaviour and population size, noise disturbance, resource use (such as drinking water consumption) and waste generation, vehicle traffic and the parking occupancy.

The available data does not provide detailed quantitative information on the practice of each NBA and the trends in recent years. However, the literature now clearly shows that any recreational activity carried out in nature disturbs the most sensitive wildlife and habitats. This disturbance increases as the number of people engaging in the activity increases, and both the data analysed in the PNMA case study and the information provided by other partner protected areas highlight a significant increase in the visitor number. The activities that cause the most disturbance to fauna and vegetation are winter snow sports (with or without ski lifts), hiking, and trail running. The strongest impacts demonstrated so far are those affecting individuals and manifest as responses ranging from escape and displacement from the most disturbed areas to the modification of behavioural patterns, whereby predominantly diurnal animals shift their daytime activities to nocturnal ones. However, there are known cases where human presence is high even during the hours of darkness, especially at dusk and dawn, thus

adding to the disturbance even during this time of day. To date, the data available on the disorder at the population level are not consistent enough to draw conclusions on this aspect.

Since there are no set values to define when the impact is “too much”, it is useful to combine the aforementioned insight with the expertise of protected area staff. Qualitative information was therefore collected, including through the creation of a Focus Group made up of leading experts in wildlife and habitat fragmentation for each protected area involved in the project. The eight experts were suggested by the individual project partners participating in the project and are mainly park rangers or people who follow the issues addressed. Each of them was interviewed about the potential disturbances to wildlife and habitats caused by human recreational activities, as perceived during their normal activities within the protected area. A summary is provided in Annex 1.

All experts agree that outdoor activities directly and indirectly disrupt wildlife and habitats. This disruption is also due to the increased use of protected areas, starting during the 2020-2021 pandemic. The most common types of disturbance are those deriving from snow activities, on- and off-piste skiing, snowshoeing, hiking, cycling, paragliding, dogs often kept off leash, climbing, wild camping, and swimming in alpine lakes. The only exception is the Swiss National Park, where the rules are very strict and the activities permitted are very limited (only hiking) and the period in which they can be carried out is very restricted (the park is closed in winter): here the disturbance is really close to zero. Table 3.3 offers an overview of what outdoor practices are tolerated in LiveAlpsNature protected areas. This can also be seen as an overview of which impacts are tolerated, and to what extent. When analysing the table, it should be noted that all these areas can be considered as strongly protected, since many Italian regional nature parks have levels of protection comparable to those of National parks in other countries (as is the case of both Aree Protette dell’Ossola e Parco naturale Mont Avic) (ALPARC, 2023). As shown in Table 3.3, most outdoor activities are specifically regulated, and sometimes prohibited, in protected areas. However, all experts highlighted that rules are often not respected and even where some of these activities are completely prohibited, they are still practiced. Sometimes, as in the case of paragliding, it is impossible to trace and fine the offenders.

	APO	TNP	NPB	SNP	PNE	ASTERS	PNMA
Hiking¹⁰	YES	YES	YES	Temporal limitations	YES	YES	YES
Dogs¹¹	Temporal limitations	YES	YES	NO	NO	NO	YES
Cycling	Spatial limitations	Spatial limitations	Spatial limitations	NO	NO	Spatial limitations	specific tracks
Climbing	Spatial limitations	Spatial limitations	Spatial limitations	NO	Spatial limitations	Equipment limitations	Spatial limitations
Ski / snowshoes	Spatial limitations	Spatial limitations	Spatial limitations	NO	Spatial limitations	Spatial limitations	Spatial limitations
Swimming	NO	Spatial limitations	NO	NO	YES	NO	NO
Flying	Spatial limitations	Spatial limitations	NO	NO	Temporal and spatial limitations	Spatial limitations	NO
Drones¹²	NO	NO	NO	NO	NO	Spatial limitations	NO
Bivouacking	Temporal and spatial limitations	Spatial limitations	NO	NO	Temporal and spatial limitations	Temporal and spatial limitations	Temporal and spatial limitations
Camping vehicles	NO	NO	NO	NO	NO	NO	NO
Picking flora¹³	NO	NO	NO	NO	NO	NO	NO
Picking minerals¹³	NO	NO	NO	NO	NO	NO	NO

Table 3.3 Activities allowed, allowed with limitations, or prohibited in the protected areas participating in LiveAlpsNature.

Note: the information reported in the table is indicative only – for the exact regulations, please refer to the official rules of each protected area.

Overall, it clearly emerges that the only activity that is accepted in every protected area is hiking. The results of the questionnaire targeted at visitors¹³, which were conducted as part of the LiveAlpsNature project in the summer season of 2025, show that hiking is the main reason for visiting nature (ranging from 69% to 82% in the participating protected areas). Indeed, in

¹⁰ While hiking is generally allowed, it must be confined to existing official trails.

¹¹ Where dogs are allowed, they must remain on a leash at all times.

¹² These activities may be permitted in specific cases (e.g., scientific and research purposes) and only with prior consent from the protected area authority.

¹³ The results (for both visitors and tourism operators) are presented in the Deliverable D.1.1.1 and its Annexes.

all protected areas, the most popular activity is hiking, followed by wildlife observation and nature contemplation, that can also be assumed to be done while walking and therefore related to hiking. Even if hiking is a low-impact activity from the individual point of view, its popularity makes its aggregate effect a major management issue. This is particularly relevant in regions that suffer from overcrowding, but also in less frequented areas it is connected to inappropriate behaviours, such as leaving the paths, letting dogs off the leash or trying to approach animals, which in turn cause habitat fragmentation and disturbance.

It is interesting to underline that, in this regard, a common tendency seems to emerge across protected areas. Visitors are concentrated on few, well maintained and well indicated itineraries, while other paths are closed or abandoned, letting nature recover these spaces. In parallel, tourism offers are proposed outside the park boundaries (or at least outside their core zones) or are specifically aimed at increasing visitor awareness about the park environment and mission. This approach requires “sacrificing” some spots, but allows nature to have much more space and time of quietness, while also diverting people outside of the most sensitive zones and/or promoting responsible behaviours.

Concerning visitor awareness, 95% of respondents to the above-mentioned survey indicated that they were aware of being in a protected area before starting to fill in the questionnaire. Interestingly, the figure appears to be in stark contrast with the experience of park managers, who frequently report the lack of knowledge about the very existence of a protected area and its rules as a main cause of forbidden behaviours. This discrepancy may, of course, be due to various factors, such as the sample size or the survey dissemination methods, the type of respondents (e.g., individuals already interested in the topic), or response biases, particularly a tendency to avoid admitting unawareness about the protected areas. The different insights emerging from the two project activities suggest the need to better understand how to reach individuals who are unaware of the protected areas and to identify the channels through which they obtain (or fail to obtain) relevant information.

For example, another problem encountered by the participants of the Focus Group is the use of social media. Although from the survey they do not appear to be the main source of information about protected areas, park staff report that photos of enchanting landscapes posted by visitors attract an increasing number of people, often belonging to the category of the so-called “first-time mountaineers” (less unaware of the fragile environment they are visiting). The experts suggested deepening our understanding of this issue by establishing targeted research programs, getting access to dedicated NBA platforms in order to correct any misinformation and raise awareness among visitors. In some cases, the dedicated figure of the digital ranger was created, with the aim to check the contents shared on the web (e.g. photos,

videos, tracks on outdoor platforms) and try to remove those that comply with park regulations¹⁴.

The responses provided by visitors regarding the impact of outdoor activities on the protected area are also noteworthy. Just under 50% of respondents considered the disturbance to wildlife and the natural ecosystem to be "medium." The question regarding habitat fragmentation received the highest percentage of "Don't know" responses (about 16%), perhaps due to a lack of knowledge about the phenomenon. Increased waste is the category perceived as having a "high impact" across the Alpine region, with an average of nearly 50%. When asked about the risk of overcrowding/overtourism, 64% of survey participants rated this category as high, 24% of users rated it as "medium," and 8% as "low." These data highlight how the threat of overcrowding in natural areas is clearly perceived by visitors, but also what are the topics where it is most important to strengthen awareness.

To conclude, the central objective of protected areas is to maintain the ecological integrity of ecosystems, understood as the combined conservation of species, habitats, and natural processes. However, for humans, they also represent areas of recreation, well-being, and, very importantly, health. It is therefore necessary to develop measures that, on the one hand, mitigate the impact of protected areas on biodiversity and habitat fragmentation, and, on the other, allow humans to visit protected areas to enjoy the physical and psychological benefits that nature can offer. More precisely, this should reflect (as it already does in strongly protected areas) in a three-step approach:

1. Ban or strongly limit the activities that have a high impact already at the individual level, either on ecosystem as a whole or on specific species
2. Define specific rules for activities that have a low impact at the individual level (e.g. hiking), by identifying the places and the behaviours that make these practices acceptable
3. Explain to visitors why these bans and limitations are implemented by protected areas, raising awareness on the impacts of each activity and promoting a broader acceptance of rules and adoption of pro-environmental behaviours

As concerns management measures and information, the following priority actions are recommended for impact assessment and mitigation:

¹⁴ See also ALPARC - Digital Management and Monitoring Technologies in Alpine Protected Areas
<https://alparc.org/alpine-resources/digital-management-and-monitoring-technologies-in-alpine-protected-areas>

- **Long-term wildlife monitoring:** implement study protocols that focus on population dynamics (reproduction and survival rates) rather than just individual behaviour, with particular attention to study aimed at identifying variations in spatial use, to understand the true extent of ecological damage over time.
- **Long-term habitat fragmentation monitoring:** monitor the possible opening of ephemeral, unofficial trails and, if necessary, restore damaged habitats or soil.
- **Long-term tourism monitoring:** implement study protocols focused on recreational activities in protected areas, providing data comparable and correlated with those collected for wildlife and habitats.
- **Education and awareness:** implement communication campaigns to raise awareness on disturbance associated with specific activities, including those that are mistakenly perceived as harmless (the "invisible disturbance" e.g., hiking, snowshoeing, ski mountaineering); promote and encourage activities offered by hiking guides, mountain guides and mountain leaders specifically trained on these issues.
- **Seasonal zoning:** establish "absolute quiet" areas (no-go zones) during critical winter and reproductive periods to ensure wildlife receives the necessary energy savings and undisturbed access to food resources.
- **Time regulation:** limit recreational activities during the night and twilight hours, so as not to interfere with species that have modified their circadian rhythms in response to diurnal anthropogenic pressure.
- **Channelling of flows:** keep visitors on official routes to preserve vegetation cover and biodiversity and avoid the creation of "ephemeral" or spontaneous trails, while also limiting the number of available tracks to prevent excessive dispersion of human presence and reduce habitat fragmentation.
- **Diverting visitors outside protected areas:** propose and provide information about activities outside the boundaries of protected areas (or outside core zones), to divert people away from the most fragile sites and reduce pressure on protected habitats.
- **Identification of "relief" areas:** where appropriate, after careful evaluation, areas could be identified where the impact is minimal or "acceptable", in order to protect more sensitive areas where the impact could be higher.
- **Numerical regulation:** where necessary, a limitation on the number of people who can access a given area or a total ban on access could be foreseen.
- **Limiting infrastructure at high altitude:** extreme caution should be exercised in evaluating any plans to build infrastructures at high altitudes, especially as concerns relocating ski facilities, to avoid the irreversible loss of remaining refuge habitats.

3.2 Indicators for assessing the impact of nature-based activities on biodiversity

3.2.1 Introduction

The preceding sections of this report have progressively built a knowledge base for understanding and managing the impacts of nature-based activities (NBAs) on biodiversity and habitats in Alpine protected areas. Section I reviewed the scientific literature on disturbance mechanisms and vegetation damage, establishing a conceptual framework of direct and indirect impacts across a range of activities. Section II applied these concepts to five case studies, illustrating the monitoring methods employed by partner protected areas and the ecological responses documented in the field. Section III examined the compatibility of NBAs with the conservation goals of differently protected areas and outlined a set of priority management actions. Taken together, these sections reveal both the breadth and the urgency of the challenge: visitor numbers are increasing, the range and diversity of activities practised in Alpine protected areas is growing, and the capacity of current monitoring systems to generate timely, comparable, and decision-relevant data remains limited.

The present section addresses this gap by proposing a structured set of indicators for the operational assessment of NBA impacts on biodiversity. The need for indicators arises directly from the management logic underpinning protected areas: conservation objectives require measurable benchmarks against which the status of ecosystems can be evaluated, trends identified, and management interventions justified. As noted in Section III, the concept of carrying capacity — understood as the maximum level of human use that an environment can sustain without compromising its ecological structures — provides a normative reference point for this exercise. While the precise quantification of carrying capacity remains contested and site-specific (Long et al., 2022; UNWTO, 1983; Zekan et al., 2022), well-chosen indicators can serve as operational proxies that signal whether human pressure is approaching, remaining within, or exceeding acceptable limits. This logic is consistent with the “Limits of Acceptable Change” (LAC) framework (Stankey et al., 1985), which shifted the focus of recreation management from the difficult question of “how much use is too much?” to the more tractable one of “what conditions are acceptable, and how do we know if they are being maintained?”

In identifying appropriate indicators for this context, reference is made to the DPSIR framework (*Driving forces – Pressures – State – Impact – Response*), widely applied in EU environmental reporting, notably by the European Environment Agency, and increasingly

adopted in protected area assessment (Niemeijer & de Groot, 2008; Pirrone et al., 2005). Within this framework, indicators can be organized along a causal chain: driving forces (e.g., tourism demand, land use) generate pressures (e.g., visitor numbers, trail intensity) that alter the state of ecosystems (e.g., vegetation cover, species distribution), producing ecological impacts (e.g., population decline, habitat fragmentation) that in turn trigger management responses (e.g., zoning, access restrictions). Monitoring indicators at multiple points along this chain makes it possible to detect problems early — ideally at the pressure stage, before irreversible ecological damage has occurred — and to evaluate the effectiveness of mitigation measures over time.

The selection of indicators proposed hereafter is guided by a set of methodological criteria:

1. **ecological relevance:** indicators should capture processes or states that are genuinely sensitive to NBA-related disturbance, as documented in the scientific literature reviewed in Section I (e.g., flight responses in ungulates, vegetation cover loss near trails, altered habitat use of galliformes)
2. **operational feasibility:** indicators must be measurable with methods realistically available to protected area staff, including the monitoring tools already deployed by partner areas (eco-counters, ranger observations, camera traps, GPS tracking platforms)
3. **interpretability:** indicators should yield values that can be compared across time, across sites, and against reference thresholds or baselines, in order to support management decisions
4. **responsiveness:** indicators should be capable of detecting change at a temporal scale relevant to management — typically one to five years — rather than only over decades
5. **generalizability:** while site-specific calibration will always be required, the indicators proposed here are designed to be applicable, at least in principle, across the range of Alpine protected areas participating in the LiveAlpsNature project, with different protection statuses and ecological contexts.

In practice, as illustrated by the case studies in Section II, no single indicator can capture the full complexity of NBA impacts on biodiversity. A monitoring system built on multiple complementary indicators — covering both the pressure side (visitor flows, activity types, spatial and temporal distribution) and the ecological response side (species behaviour, habitat condition, population trends) — is therefore recommended.

3.2.2 Proposed indicators

Table 3.4 presents a set of twelve core indicators for the assessment of NBA impacts in Alpine protected areas, organized within the DPSIR framework. The set covers three interrelated dimensions of the impact chain. The first four indicators (I.1–I.4) address the pressure side of the DPSIR chain: they capture visitor numbers (I.1), individual behaviour and regulatory compliance (I.2), the spatial extent of visitor presence beyond official trails (I.3), and the structural fragmentation of habitat attributable to the trail network (I.4). A fifth indicator (I.5) specifically targets the winter season, mapping visitor distribution during snow sports activities and its spatial overlap with critical wintering and breeding habitat for sensitive species. This indicator is based on the standardised diagnostic methodology developed between 2010 and 2012 by the ONCFS (Office National de la Chasse et de la Faune Sauvage) under research convention ONCFS/FDC 38 (ONCFS, 2012), subsequently adopted by Aree Protette dell'Ossola within the RESICETS project, and has already demonstrated its operational feasibility in the Alpine context. Three indicators (I.6, I.7, I.8) assess ecological impacts on the most disturbance-sensitive vertebrate groups documented in the literature reviewed in Section I — alpine galliformes, ungulates and cliff-nesting raptors respectively. A further two (I.9, I.10) address the physical state of vegetation communities and trail-soil condition. Indicator I.11 proposes the deployment of systematic camera trap grids combined with occupancy modelling (MacKenzie et al., 2002, 2006) to simultaneously estimate wildlife habitat use and human presence intensity at the landscape scale, enabling an integrated, spatially explicit assessment of the overlap between visitor pressure and species distribution. Finally, indicator I.12 addresses water quality in alpine lakes and streams, capturing the cumulative pressure of bathing, picnicking and inadequate sanitation through physicochemical, microbiological and biological monitoring aligned with the Water Framework Directive (Directive 2000/60/EC – EU, 2000); this is particularly relevant given the growing practice of summer bathing in high-altitude lakes, whose ecological impacts on sensitive aquatic habitats remain poorly quantified.

Each indicator is characterized along four operational dimensions, assessed on a three-level ordinal scale (Low / Medium / High): (i) overall methodological complexity of the monitoring protocol; (ii) human resources required in terms of field time, technical expertise and coordination effort; (iii) technological complexity and instrumentation requirements; and (iv) estimated financial cost of a standardised, repeatable implementation. These ratings refer exclusively to routine monitoring once a protocol is operational; initial setup costs (e.g., camera trap grid installation, baseline vegetation surveys, eco-counter placement) are invariably higher and should be factored into multi-year resource planning.

Finally, it is important to emphasise that the selection of indicators was also based on the input provided by the partners during the preliminary phase of the LiveAlpsNature project. Through an internal survey within the partnership, key information was gathered to structure not only the surveys dedicated to Activity 1.1, but also other parameters agreed upon by the partnership, such as: the identification of flagship/target species, the applicability of monitoring methodologies, and the perceived level of impact for each outdoor discipline. Through the administration of the questionnaire, it was therefore possible to define the baseline scenario for Activities 1.1, 1.2 and 1.3, including the schematisation of the main impact indicators to be taken into account.

#	Indicator	Description	DPSIR	Target species / habitats	Complexity	Human resources	Technological complexity	Financial cost
I.1	Visitor flow monitoring	Quantitative monitoring of the number of visitors accessing the protected area, disaggregated by entry point, trail segment, season and time of day. Implemented via automatic people counters (eco-counters), ranger patrol counts and, where available, data from parking sensors or access ticket records. Provides the fundamental pressure baseline against which all other indicators are interpreted.	P	All habitats and species	Low	Low	Low	Low
I.2	Visitor behaviour survey	Systematic collection of data on visitor behaviour through structured face-to-face interviews or self-administered questionnaires, administered to a random sample of visitors at key access points. Variables recorded include: type of activity practised, trail itinerary and duration, compliance with area regulations (e.g. leash rules for dogs, trail restrictions), awareness of potential impacts on biodiversity, and information sources used. Complements the quantitative flow data of I.1 with qualitative and behavioural information essential for targeted awareness-raising and communication measures.	P	All habitats and species; particularly relevant in combination with indicators I.4, I.5, I.6	Low	Medium	Low	Low
I.3	Visitor spatial behaviour and off-trail movement	Assessment of the spatial distribution of visitors relative to the official trail network, including detection of off-trail movements, informal path use and access to restricted or sensitive zones. Data sources include ranger field observations, camera traps at key access points, and analysis of geotagged tracks from outdoor platforms (e.g. Strava, Wikiloc, Komoot). Enables quantification of the effective disturbance footprint beyond official trail corridors.	P	All habitats; particularly relevant for alpine grasslands (Natura 2000 habitats 6170, 6230*) and disturbance-sensitive species in buffer zones	Medium	Medium	Medium	Medium

#	Indicator	Description	DPSIR	Target species / habitats	Complexity	Human resources	Technological complexity	Financial cost
1.4	Trail network fragmentation index	GIS-based measure of habitat fragmentation attributable to the density and spatial extent of the trail network (official and informal) per unit surface area. Computed as total trail length per unit area (km/km ²) and, preferably, as effective mesh size (m_{eoo} , Jaeger 2000), which quantifies the probability that two randomly chosen points in the landscape are connected without crossing a disturbance corridor. Periodic reassessment via GIS comparison of orthophotos or LiDAR-derived products identifies expansion of the informal trail network over time.	P / S	All natural and semi-natural habitats; particularly relevant for wide-ranging species (ungulates, ursids, carnivores) and habitat continuity requirements under Natura 2000	Medium	Low	Medium	Low
1.5	Winter spatial distribution of visitors and overlap with wildlife habitat	Mapping of the spatial distribution of winter recreational users (skiers, snowshoers, ski mountaineers) and quantification of their overlap with habitat areas of high conservation value for winter-sensitive species. The protocol is based on the standardised methodology developed between 2010 and 2012 by the ONCFS (Office National de la Chasse et de la Faune Sauvage) under research convention ONCFS/FDC 38 (ONCFS, 2012): wintering habitat is subdivided into 1-hectare grid cells, each prospected over seven consecutive days to record both species presence signs (tracks, droppings igloos for galliformes) and the type and intensity of recreational use. The resulting overlap index identifies zones of critical conflict. This methodology was subsequently adopted by Aree Protette dell'Ossola within the RESICETS project and underpins the design of seasonal quiet zones in the Ossola protected areas.	P / I	Black grouse (wintering and lekking sites), rock ptarmigan, mountain hare <i>Lepus timidus varronis</i> , ungulates (winter range); subalpine and alpine habitats under snow cover	Medium	Medium	Low	Low

#	Indicator	Description	DPSIR	Target species / habitats	Complexity	Human resources	Technological complexity	Financial cost
1.6	Alpine galliform breeding success and seasonal habitat use	Annual monitoring of breeding success (number of chicks per hen in late summer) and seasonal spatial distribution of key indicator galliform species (black grouse <i>Lyrurus tetrix</i> , rock ptarmigan <i>Lagopus muta</i> , capercaillie <i>Tetrao urogallus</i>) in relation to visitor pressure zones. Conducted via standardised point count surveys, dawn lek counts and camera trap grids. Season-specific comparison of occupied habitat vs. disturbed areas enables detection of disturbance-induced avoidance and reproductive failure (Arlettaz et al., 2007; Storch, 2013)	I	Black grouse, rock ptarmigan, capercaillie; forest ecotone and alpine grassland habitats	High	High	Medium	Medium
1.7	Ungulate spatial distribution and disturbance-related avoidance	Multi-year monitoring of the spatial distribution and seasonal movements of key ungulate species (Alpine ibex <i>Capra ibex</i> , chamois <i>Rupicapra rupicapra</i> , red deer <i>Cervus elaphus</i> , roe deer <i>Capreolus capreolus</i>) in relation to visitor pressure levels. Data collected via standardised ranger observations, camera trap networks and, where applicable, GPS collar data. Flight initiation distance (FID) and proportion of sightings in the vicinity of high-use trails are used as disturbance proxy metrics (Frid & Dill, 2002; Tablado & Jenni, 2017).	I	Alpine ibex, chamois, red deer, roe deer; alpine grasslands, rocky habitats and forest margins	Medium	Medium	Medium	Medium
1.8	Raptor nesting success and proximity to recreational disturbance	Monitoring of nesting success (eggs laid, chicks fledged) and nest site fidelity for disturbance-sensitive raptor species (golden eagle <i>Aquila chrysaetos</i> , peregrine falcon <i>Falco peregrinus</i>) in relation to the spatial and temporal distribution of recreational activities — particularly climbing, paragliding and trail running. Nest abandonment rates and minimum approach distances by visitors are recorded as impact proxies.	I	Golden eagle, peregrine falcon and other cliff-nesting raptors; rocky habitats (Natura 2000 habitat 8210)	High	Medium	Low	Low

#	Indicator	Description	DPSIR	Target species / habitats	Complexity	Human resources	Technological complexity	Financial cost
I.9	Vegetation cover and floristic composition along trail transects	Standardised vegetation transects along selected trail segments, measuring: percentage bare soil, total vegetation cover, vascular plant species richness, and proportion of native vs. alien or ruderal species. Conducted in accordance with Braun-Blanquet phytosociological methodology or simplified cover-class protocols. Baseline surveys followed by periodic reassessment (every 2–5 years) document trampling-induced community shifts, including the decline of disturbance-sensitive lichens and non-vascular plants and the expansion of ruderal species (Ballantyne & Pickering, 2015; Jägerbrand & Alatalo, 2015).	S / I	Priority Natura 2000 habitats (6170, 6230*, 4060, 8110); vascular plant and bryophyte/lichen communities	High	High	Low	Medium
I.10	Trail degradation and soil erosion index	Physical assessment of trail condition along representative segments, measuring: trail tread width, incision depth, percentage of exposed mineral soil and extent of erosion features (rills, gullies, root exposure). Ratings applied using standardised condition classes (Marion & Leung, 2001). Informal trail formation is mapped via periodic GIS comparison of orthophotos or LiDAR-derived products. Provides a direct state indicator of cumulative physical habitat degradation attributable to trampling.	S	All natural and semi-natural habitats traversed by trails; particularly subalpine and alpine soils characterised by slow recovery rates	Low	Medium	Low	Low
I.11	Wildlife and visitor occupancy models via systematic camera trapping	Deployment of a systematic camera trap grid across the protected area to simultaneously estimate the occupancy and detection probability of target fauna species and the intensity of human presence (visitors, domestic animals). Data are analysed within a hierarchical occupancy modelling framework (MacKenzie et al., 2002, 2006), allowing estimation of species' habitat use while accounting for imperfect detection. Co-occurrence models explicitly quantify the spatial relationship between wildlife occupancy and visitor pressure, identifying areas of high ecological sensitivity and informing zoning decisions. Integrates and complements the species-specific indicators (I.6, I.7, I.8) with a landscape-level synthesis.	I / S	All vertebrate species of conservation interest; particularly ungulates, galliformes and mesocarnivores; all natural habitat types within the camera grid	High	Medium	High	High

#	Indicator	Description	DPSIR	Target species / habitats	Complexity	Human resources	Technological complexity	Financial cost
I.12	Alpine water body quality index	Physicochemical and microbiological monitoring of surface waters (alpine lakes, streams and ponds) to detect recreation-related degradation. Parameters measured include: turbidity, pH, dissolved oxygen, total nitrogen and phosphorus (nutrient load from bathing, picnicking and waste), faecal indicator bacteria (E. coli, intestinal enterococci) as proxies for sewage and bathing-related contamination, and, where applicable, concentration of sunscreen-derived compounds (e.g. benzophenone, octocrylene) as tracers of swimming activity. Sampling is conducted at reference sites (outside recreational influence) and at impacted sites (bathing areas, frequented shores) to enable before-after/control-impact (BACI) comparisons. Where relevant, biological quality elements (macroinvertebrate assemblages, phytobenthos) are assessed in accordance with Water Framework Directive (WFD, Directive 2000/60/EC) standard methods to provide an integrative measure of ecological status. The indicator captures cumulative pressure from bathing in alpine lakes — a practice widespread in summer and often incompatible with the conservation status of high-altitude water bodies — as well as from inadequate sanitation infrastructure near huts and trails.	P / S	Alpine lakes, streams and high-altitude water bodies (Natura 2000 habitat 3110, 3130, 3140, 3160); aquatic macroinvertebrates, phytobenthos; amphibians (where present)	Medium	Medium	Medium	Medium

Table 3.4 Proposed indicators for the assessment of NBA impacts on biodiversity in Alpine protected areas. DPSIR key — P: Pressure | S: State | I: Impact. Rating scale: Low / Medium / High refers to routine monitoring implementation, excluding initial set-up costs.

Note: The Response component of the DPSIR framework is addressed in the management recommendations presented in Section III of this report and is therefore not represented among the indicators listed here.

Note: Indicator I.5 is based on the standardised protocol developed by ONCFS (2012) for the simultaneous mapping of wintering galliform habitat and winter recreational use. See main text and bibliography for full reference.

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The LiveAlpsNature project (ASP0500464) is co-funded by the European Union through the Interreg Alpine Space programme.

