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Editorial

This editorial was written during COP30 in Belém, Brazil. The United Nations Framework Convention on Climate Change (UNFCCC) launches the Conference of the Parties (COP) each year. This body is responsible for making decisions on how countries will implement their commitments to tackling climate change. The aim of COP30, held in November 2025, was to encourage voluntary climate action from civil society, businesses, investors, cities, states and countries, with the goal of intensifying emission reductions, climate adaptation, and the transition to sustainable economies.

Just a few weeks earlier, in October 2025, the 29th IUCN World Conservation Congress took place in Abu Dhabi, United Arab Emirates. This event brought together nature conservation experts, leaders and decision-makers. The Congress aimed to advocate for the transformative change needed to secure a sustainable future for both nature and humanity.

In September 2025, the 5th World Congress of Biosphere Reserves, convened by UNESCO, took place in Hangzhou, China. This congress, held every ten years, evaluates progress, shares experiences and determines the future direction of the MAB (Man and the Biosphere) Programme. It also shapes the 2026–2035 MAB Strategy and Action Plan.

These and many other meetings at regional, national and international levels emphasised the urgent need for action on biodiversity loss, climate change, water insecurity, sustainable development and so on, recognising that these challenges are interconnected and require holistic solutions.

In this issue of eco.mont, we present examples from around the world that demonstrate the importance of providing a platform for studies in mountain protected areas, as well as tackling the aforementioned challenges. The authors in this issue write about becoming active and initiating structural changes at a regional level, analysing management models, studying and monitoring biodiversity, examining the factors influencing mountaineers' spending behaviours, and facilitating the presentation and discussion of scientific findings within the community.

Parque Andino Juncal is situated in the High Andean wetlands playing a strategic role in water provision, climate regulation and biodiversity conservation. Aldana Calderón-Archina, Leandro Manuel Alvarez, Andrés Moreira-Muñoz & Pablo Mansilla Quiñones report on climate adaptation and resilience strategies as well as on the protests of the installation of mining projects in the area.

The study on the UNESCO Biosphere Reserve Mont Viso as a model region for economically sustainable development in the Cottian Alps by Carlotta Sauerwein-Schlosser focuses on structural conditions shaping the actions of the UNESCO Biosphere Reserve. It conceptualizes territorial agency as the capacity of protected areas to initiate and sustain structural transformation.

Maria Thaís Affonsoon presents the concept on how to benchmark different landscape management models based on their ability to minimize trade-offs using the UNESCO Biosphere Entlebuch (UBE) as a case example.

Andrea Battisti, Daniele Stellin and Massimo Bocca's study of the butterfly hotspot in the Mont Emilius Massif in north-western Italy presents the first comprehensive checklist of butterflies (Papilionoidea) for this area. The data confirmed 140 butterfly taxa out of a total of 146 for the area; these represent 50.3% of Italian butterfly species. Dana Repáňová and Juraj Švajda ask whether adequate and relevant biodiversity data is being collected. Using the Malá Fatra National Park in Slovakia as a case study, they highlight the need for more intensive mapping efforts to improve our understanding of the area's biodiversity and species distribution.

The study on determinants influencing the spending of mountaineering in Spain's Protected Natural Areas by Víctor Dorado & Estela I. Farías-Torbidoni aims to analyse the determinants influencing direct spending of mountaineers on different peaks. Remarkably, the research revealed *overcrowding* as a substantial predictor of mountaineering expenditure.

Insights from the Research Symposium SNP+ 2025 with the topic *Landscape evolution* give Stefanie Gubler, Roger Keller, Angelika Abderhalden, Linda M. Feichtinger, Thomas Rempfler & Simon Aeschbacher. The second edition of the Research Symposium SNP+, organized on the occasion of the 111th anniversary of the Swiss National Park (SNP), explored landscapes as a multidimensional phenomenon.

These contributions underscore the essential role of mountain protected areas as laboratories for learning, collaboration and innovation. As global commitments intensify, such place-based research offers valuable guidance for shaping resilient futures. We hope this issue inspires continued dialogue and decisive action across disciplines and regions.

Valerie Braun – co-editor of eco.mont

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The Mont Avic – Mont Emilius Massif (NW Italy): a confirmed butterfly hotspot (Lepidoptera, Papilionoidea)

Andrea Battisti, Daniele Stellin & Massimo Bocca

Keywords: Alps, Alpine, Aosta, Erebia, Pollinators

Abstract

Species inventories are fundamental to understanding biodiversity and guiding conservation efforts. This study presents the first comprehensive butterfly (Papilionoidea) checklist for the Mont Avic – Mont Emilius Massif (Northwest Italy), a Special Protected Area within the Natura 2000 network. The area includes four additional Special Areas of Conservation and the Mont Avic Natural Park. Data collected between 2019 and 2024 confirmed 140 taxa of butterflies out of 146 total for the area, these last representing 50.3% of the Italian fauna. The butterfly community includes: i) two new species for the Aosta Valley region (*Apatura ilia* and *Neptis rivularis*); ii) 17 newly recorded taxa for the study area; iii) four species of conservation concern listed in the European Habitats Directive 92/43/EEC (*Phengaris arion*, *Parnassius apollo*, *Euphydryas aurinia*, *Zerynthia polyxena*); iv) a significant proportion of species endemic to the mountains of Southern Europe (11.6%), particularly within the genus Erebia (15 species). Additionally, we provide distributional, ecological or conservation insights for 28 taxa of particular interest.

Profile

Protected area

Special Protected Area

Mont Avic and Mont Emilius

Mountain range

Alps, Italy

Introduction

Mountain regions host a remarkable biodiversity driven by diverse climatic conditions, steep environmental gradients and complex topography, which together create a wide variety of habitats and ecological niches. In recent decades, rapid environmental changes have driven a global decline in species (Ceballos et al. 2015), particularly among habitat-specialist taxa in mountain and alpine biomes (Beniston 2003; Rödder et al. 2021). Understanding species assemblages within these biomes is therefore crucial to addressing these challenges and developing effective conservation strategies.

Pollinating arthropods are fundamental to ecosystem functioning (Ghazanfar et al. 2016; Muinde & Katumo 2024) and serve as effective bioindicators due to their rapid response to environmental disturbances and some groups being easy to identify at lower taxonomic levels (Gerlach et al. 2013). These traits make them ideal models for studying the impacts of habitat loss, fragmentation and climate change, key drivers of biodiversity loss, particularly in the Alps and in the alpine environment (Inouye 2020). Despite their ecological role, knowledge gaps with regard to distribution remain across the Alps, especially in remote or little-known areas.

Butterflies, a key insect group, play an important role in national monitoring schemes (Sevilleja et al. 2020) and multi-taxa approaches (Viterbi et al. 2013). The Northwestern Alps host some of Europe's most important areas for species diversity and endemism, which are considered Prime Butterfly Areas by Van Swaay et al. (2006) and Balletto et al. (2010). The Mont Avic Natural Park (hereinafter MANP) in the Western Alps is already recognized for its butterfly diversity (Brockmann et al. 1993; Pensati 2007–2008). However, little information is available on the enlarged sector of the Mont Avic – Mont Emilius massif, a European bird protection site (Directive 2009/147/EC). This area also includes four Special Areas of Conservation for habitats and species of conservation concern, and it remains understudied for its arthropod diversity, especially at higher altitudes.

As part of the Italy-France cross-border cooperation project *Alcotra* (2014–2020), the specific initiative no. 3896 *COBIODIV* (more info at: https://www.interreg-alcotra.eu/it/cobiodiv-conoscere-la-biodiversita-e-gli-ecosistemi-proteggerli-meglio-insieme) aimed to promote *hidden biodiversity data acquisition activities*, addressed to specific target species in the surroundings of the Mont Avic – Mont Emilius massif. The project focuses on species listed in the European Habitat Directive 92/43/EEC and on rare or endemic species.

Monitoring biodiversity in protected areas is crucial for assessing their effectiveness and providing data for proper management (Le Saout et al. 2013; Thomas & Gillingham 2015; Gray et al. 2016). Since its establishment, the MANP has prioritized scientific research to support evidence-based management and effective conservation strategies (Bocca et al. 2009).

We believe it is crucial to share our findings on the butterflies of the Mont Avic – Mont Emilius massif to expand knowledge of local butterfly diversity and provide a resource for managing and conserving Alpine species and habitats. Our work also establishes a baseline for future research at the local level, especially regarding climate change and altitudinal shift.

Materials and methods

The study area corresponds to the Special Protection Area (SPA) IT1202020 *Mont Avic and Mont Emilius*, part of the European Natura 2000 Network (Trochet & Schmeller 2013), which is entirely located in the Aosta Valley, in the Northwestern Alps. This SPA includes four additional Special Areas of Conservation (SACs): 1) IT1206054 *Vallone del Grauson*; 2) IT1205065 *Vallone dell'Urtier*; 3) IT1205100 *Ambienti d'alta quota della Vallée de l'Alleigne*; and 4) IT1202000 *Mont Avic Natural Park*, a locally protected area that has undergone two recent boundary revisions: on 31 May 2003, with an expansion towards the Champorcher Valley (Regional President's Decree No. 298), and more recently, on 16 May 2023 (RPD No. 390), further extending towards the Clavalité Valley.

This area encompasses a vast territory of the Northewestern Alps, extending from the Cogne Valley in the west along the entire orographic right side of the Dora Baltea River and reaching the border with the Piedmont region in the southeast. The SPA covers an area of 31,544 hectares, with an altitude range spanning 900 to 3,559 meters (Mont Emilius), and features over 20 peaks rising above 3,000 meters (Mont Avic at 3,006 meters).

Five sectors were identified to map the species distribution: i) W sector – Grauson and Urtier valleys; ii) NW sector – Mont Emilius area; iii) N sector – Clavalité and Saint-Marcel valleys; iv) NE sector – Mont Avic area; and v) SE sector – Champorcher valley. Data collection at lower altitudes (from 450 m) was limited to the NE and SE sectors, whereas all other data points are located at higher elevations (from 1,000 m). Data collection extending beyond the formal administrative boundaries of the former SPA, resulting in a study area of at least 41,000 ha (Figure 1). The expanded areas are evident from the data distribution shown in Figure 1. This mountain area hosts a remarkable diversity of habitats (Figure 2), including 28 types listed in Annex I of the *Habitat* Directive 92/43/EEC, six of which are of priority concern (*). Among these, habitats of particular interest for butterflies include calcareous and siliceous grasslands, which are often rich in herbaceous species (codes 6110, 6150, 6170, 6210, 6230*, 6240), peat bogs (7110*, 7140), alpine pioneer formations of the Caricion bicoloris-atrofuscae (7240*), scree and rock faces (8110, 8120, 8130, 8210, 8220, 8230), and limestone pavements (8240*) (Bocca et al. 2016).

Original data were collected in the whole study area and from 2019 to 2024 by active sampling from March to September, from 500 to 3,559 meters of altitude, as part of three different initiatives: (1) the *COBIODIV* project, which focused across the entire study area on eight taxa of interest (*Parnassius apollo*, *P. phoebus*, *Phengaris arion*, *P. alcon ssp. rebeli*, *Euphydryas aurinia*, *Colias palaeno*, *Apatura iris and Zerynthia polyxena*). For these target species the COBIODIV project required the identification of suitable sites where standardized and repeatable long-term sampling could be carried out, following the guidelines established in Italy by ISPRA (Institute for Environmental Protection and Research in Italy) for the monitoring of the species listed in the annexes II and IV of the *Habitat* Directive 92/43/EEC (Stoch & Genovesi 2016). Given the limited knowledge about butterflies in the study area, achieving this goal required extensive field exploration within each valley to locate suitable habitats for the target species and to confirm their presence. Numerous surveys were therefore conducted in many sites, each time investigating the entire butterfly community present, often by explorative linear transects carried out as described in Van Swaay et al. (2012). All collected data, whether from standard sites later selected or from less suitable sites for the target species (including occasional records or non-standardized observations), were georeferenced and archived. These data significantly contributed to improving faunistic and distributional knowledge of butterflies in the study area, together with data collected through the following two initiatives; (2) a standardized monitoring by linear transects as part of the European Butterfly Monitoring Scheme (eBMS; Sevilleja et al. 2020) at three localities, Veulla (1,290 m), Costaz (1,550 m) and Pian Inseta (2,350 m) (see Figure 1), partially supported by the MANP with the valuable support of the park rangers, coordinated by the park ranger Gianna Bosio thanks to her expertise in the field; and (3) additional original data from personal observations (free net sampling and occasional records) by one of the authors (AB) and by Gianna Bosio, with a particular focus on butterfly communities in remote or little-known localities. In addition, previous lists come from the first two inventories promoted by the MANP, which covered the Chalamy Valley (NE sector) from 450 to 2,350 meters, both within and outside the Natural Park (Brockmann et al. 1993); and the Champorcher Valley (SE sector) within the park boundaries from 1,850 to 2,910 meters (Pensati 2007–2008).

Species identification was primarily done in the field, with challenging taxa identified later through photographs or genitalia examination for the genera *Pyrgus, Melitaea,* and *Hipparchia*. Taxonomy follows the most recent nomenclature by Wiemers et al. (2018), considering some taxa classified as true species in Italy by Balletto et al. (2014) as subspecies. The ecological preferences (humidity and temperature) presented for each species follow those of Balletto and Kudrna (1985).

Results

We collected 4,885 recent original data, observing 140 taxa (Table 1), with mesophilous species predominating, followed by thermophilous / xerophilous species (23.97%) and microthermal / hygrophilous species (4.11%).

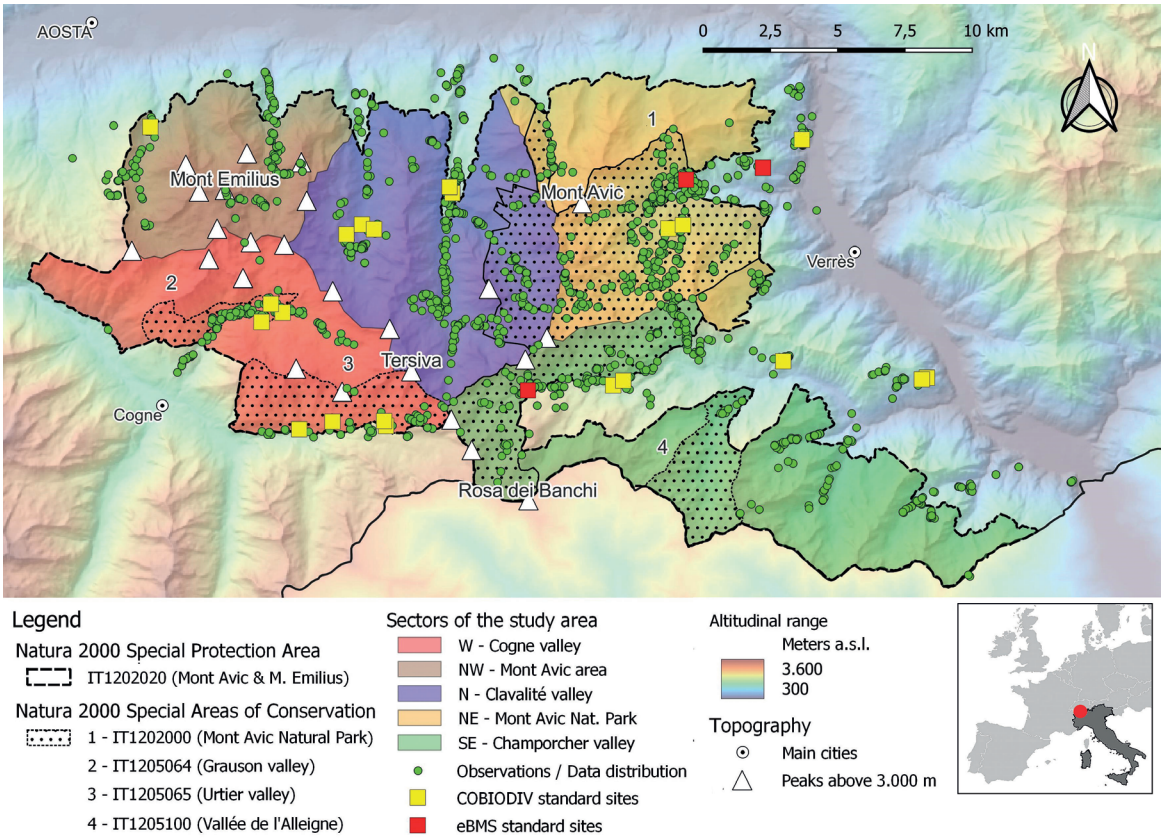


Figure 1 – The study area of the Mont Avic and Mont Emilius massif at the southern border of the Aosta Valley region, Northwest Italy. Red dots represent original data from the last five years, with each dot corresponding to one or more observations within an area of approximately 100 m radius. The figure was produced using QGIS (version 3.22; QGIS Development Team); DTM data source: https://mappe.regione.vda.it/pub/geonavitg/geodownload.asp?carta=DTM0508; Natura2000 spatial data source: https://www.eea.europa.eu/data-and-maps/data/natura-14/natura-2000-spatial-data); Map Design: Andrea Battisti 2025.

Two taxa are reported for the first time for the Aosta valley region: *Apatura ilia* and *Neptis rivularis*; and 15 more taxa are reported for the first time for the study area*: Brenthis hecate*, *Coenonympha gardetta* ssp. *darwiniana*, *Colias crocea*, *C. palaeno*, *Erebia medusa*, *E. meolans*, *E. pluto*, *E. triarius*, *Kretania trappi*, *Lybithea celtis*, *Polyommatus daphnis*, *Pyrgus cacaliae*, *P. armoricanus*, *Satyrium spini* and *Thecla betulae*. The total proportion of restricted endemics from the mountains of Southern Europe reaches 11.6% (17 species), including nine taxa exclusive to the Alps (*Pyrgus cacaliae*, *P. carlinae*, *Lycaena hippothoe* ssp. *eurydame*, *L. tityrus* ssp. *subalpina, Kretania trappi*, *C. gardetta* ssp. *darwiniana* (without ruling out the *ssp. macrogamma*), *Oeneis glacialis*, *Erebia mnestra*, *E. melampus*). Additionally, eight more taxa are distributed in the Alps and one more mountain range among the Apennines, Pyrenees or Dinaric Alps (*Euchloe simplonia*, *Euphydryas aurinia* ssp. *debilis*, *E. cynthia*, *Melitaea varia*, *Coenonympha gardetta*, *Erebia arvernensis*, *E. pluto*, *E. montana*). The genus *Erebia* is the most represented, with 15 species (10.3%).

Four species of conservation concern at the European level, as listed in Annex II and/or IV of the Habitat Directive 92/43/EEC, are present: *Phengaris arion*, *Parnassius apollo*, *Euphydryas aurinia* and *Zerynthia polyxena.*

Discussion

The study area hosts a total of 146 taxa, of which 140 were confirmed by the original data of the present study and six were only reported in Brockmann et al. (1993), representing 50.3% of the entire Italian diurnal butterfly fauna (Balletto et al. 2014). Among these, two taxa are not considered valid species by Wiemers et al. (2018): *Coenonympha gardetta* ssp. *darwiniana* and *Lycaena tityrus* ssp. *subalpina*. Two decades ago, Brockmann et al. (1993) only reported *L. tityrus* in the Chalamy Valley, with observations at two different altitudes: at 500 and 2,200 m. Thanks to our recent records, which only refer to *L. t. subalpina*, exclusively observed above 1,290 m, we can deduce that the observations above 2,000 m by Brockmann et al. were probably referred to the latter, leaving us to consider that both *ssp. subalpina* and *ssp. tityrus* are present in the study area, each occupying different elevational ranges.

Within the formal boundaries of the MANP, we can confirm the presence of 113 species. Three of the newly recorded species had already been mentioned by Brockmann et al. (1993) as likely present and have now been confirmed: *C. gardetta* ssp. *darwiniana*, *C. palaeno* and *E. pluto*. Similarly, 15 years ago, Pensati (2007–

2008) recorded *E. aethiops*, *E. gorge* and *P. phoebus* for the first time within the Park's SE sector. We believe that nearly all newly observed species have likely been historically present but remained unrecorded due to sampling deficiencies.

Even in protected and well-managed areas, conservation efforts may be limited by ongoing long-term trends linked to recent climate changes, as observed on larger scales (Holsinger et al. 2019). Although four species are listed in Annex II and/or IV of the Habitats Directive 92/43/EEC, the IUCN Red List classifies them as Near Threatened or Least Concern in Italy (Balletto et al. 2015). The only exception is a fifth species, *Kretania trappi*, which is not included in the annexes of the Habitats Directive but is classified as Vulnerable in Italy. At the European level (Van Swaay et al. 2010), only *Phengaris arion* is Endangered, while 14 species are Near Threatened (see Table 1).

By comparing species diversity across four protected areas in the Alps, each representative of butterfly hotspots: i) the Maritime Alps (Bonelli et al. 2015) – referring to about 28,000 ha; ii) the Mont Avic – Mont Emilius Massif (present study) – 41,000 ha; iii) the Veglia Devero Natural Park (Battisti et al. 2019) – 15,000 ha; and iv) the Stelvio National Park (Bonifacino et al. 2017) – 130,000 ha, we can assess their total species richness, which amounts to 150, 146, 107 and 144 species respectively. The proportion of southern European mountain endemic species of these areas is: 9%, 12%, 12% and 8% respectively. These numbers highlight the remarkable diversity of species across the Alps, including the Mont Avic – Mont Emilius Massif. Nonetheless, species distribution has been shaped by geography and Quaternary glaciations, with glacial refugia and recolonization from surrounding areas contributing to the high biodiversity and presence of unique local endemics in these sectors of the Alps.

Amid the ongoing sixth mass extinction (Ceballos et al. 2015), this study underscores the need to preserve habitats and species in the study area for future generations. Locally, this requires preventing new infrastructure and mitigating overgrazing and over-tourism in both managed and wild areas. Particular attention should be given to ecotones, such as grassy lake, pond banks, forest-grassland and rock-grassland ecotones, but especially to arid medium-altitude slopes, which host the highest diversity within the 1,000–2,500 m belt, consistent with biodiversity patterns observed in the Western Alps by Viterbi et al. (2013).

A discussion of 28 species of interest follows, grouped by topic and alphabetically:

Topic 1 - New taxa for the study area

Apatura ilia – New species for the Aosta Valley region. A single observation was recorded on 4 August 2022 at 400 m in the NE sector, along the lower Chalamy stream; *Brenthis hecate* – A single observation was recorded on 21 June 2023 at 730 m in the NE sector (the specimen at: https://www.inaturalist.org/observations/168622141). This species appears very rare in the Aosta Valley, with only one other record by Hellmann et al. (1999); *Coenonympha gardetta* ssp. *darwiniana* – This taxon is well represented in the Ossola Valley (Piedmont), while *C. macromma* has recently been confirmed in the Western Alps (Capblancq et al. 2019). In this study, five records likely refer to *C. darwiniana* (three specimens at: https://www.inaturalist.org/observations/51001628; …/51001855; …/55679942). Previously, it was recorded in the region only above 2,000 m at Gressoney-La-Trinité (Hellmann et al. 1999), suggesting the left side of the Dora Baltea River as its eastern distribution limit. Schmitt and Besold (2010), who supported species status for all four taxa in this group, proposed *C. darwiniana* as a possible hybrid between *C. arcania* and *C. gardetta*, originating from a Würm glacial refuge and later expanding. Almost all observations above 1,700 m in the study area refer to *C. gardetta* (73 recent observations), while *C. arcania* is well represented from the valley floor up to 1,800 m (94 rec. obs.). In our study area, the closest observations of these two taxa occur on the right side of the Chalamy valley, within the MANP. Here, *C. arcania* is common up to 1,600 m around *La Veulla*, with a single specimen recorded at 1,700 m in the forest; just 200 m away, *C. gardetta* is common at *Leser Desot* (1,785 m). In five other instances, we observed a short gap (0.7–1.2 km) between the highest *C. arcania* and the lowest *C. gardetta* along the altitudinal gradient in the N, NE and SE sectors. The five records of *C. gardetta* ssp. *darwiniana* were all above 1,800 m, specifically near *Leser Damon*, *Vallette Lake* and *Muffé Lake*, where the two main taxa were observed at their shortest distances. We do not rule out the presence of a *C. darwiniana* population, but we consider it a rare taxon in our study area. However, given its low occurrence density, the possibility of true hybrids cannot be excluded, and it could also be *C. macromma*. This should be supported by the fact that in northern Piedmont *C. darwiniana* is generally common and widespread, but sympatry with *C. gardetta* is not reported (Battisti et al. 2019); *Colias crocea* – This species has been quite common in recent years, with records from 15 localities, including at 2,800 m. Surprisingly, despite being an easily identifiable common species, it was not recorded in the past in the area, and is the only species showing a clear increase in the last decade. This could suggest a recent colonization, or dispersal, to higher altitudes, possibly driven by rising temperatures and decreasing precipitation in northern Italy (Kotlarski et al. 2023; Mombrini et al. 2023); *Colias palaeno* – Already cited as a probable presence by Brockmann et al. (1993), due to the presence in the MANP of *Vaccinium uliginosum* ssp. *microphyllum* (Lange) Tolm. (= *Vaccinium gaultherioides* Bigelow) (Bovio 2014; FLORAVDA 2025). Recently, *C. palaeno* was confirmed with 12 observations from six localities, in both wet and dry (Figure 2e) open shrublands with both *V. uliginosum* L.



Figure 2 – Habitat examples from the sectors of the study area: a) Mont Emilius with high altitude slopes, NW sector; b) High Urtier valley, W sector; c) Mont Avic Natural Park, NE sector; d) habitat diversity within the small valleys in the N sector; e) alpine dry shrublands, W sector; f) deciduous forests with clearings above 1,000 m, SE sector. © Andrea Battisti (all pictures)

and *V. myrtillus* L.; *Erebia pluto* – Confirmed above 2,600 m throughout its habitat (Figure 2a), with observations from eight localities; *Kretania trappi* – The rarest European species observed in our study. The first confirmed record originates from the W sector thanks to the fieldwork of Panarietti's master's thesis

(2023). In 2024, a few additional observations were confirmed in the N sector; *Lybithea celtis* – Confirmed by a few observations from a single location at 500 m. It is likely more widespread at lower altitudes in the NE and SE sectors, where the host plant *Celtis australis* L. is known up to 500 m (Bovio 2014; FLORAVDA 2025); *Neptis rivularis* – New species for the Aosta Valley region. A single observation was recorded on 4 August 2022 at 400 m in the NE sector, along the lower Chalamy stream. *Polyommatus daphnis* – This species is known from a few thermophilic locations across the Aosta Valley (Hellmann et al. 1999). In the study area, it is confirmed from a new site: a thermophilic slope in the N sector, featuring rocky outcrops, Scots pine, and herbaceous vegetation. The species was observed there on 19 July 2024, at 1,130 m, close to its known altitudinal limit in Northwest Italy; *Pyrgus cacaliae* – A single specimen was collected on 20 July 2024 at 2,490 m in the N sector, with identification confirmed by genitalia examination. As noted by Hellmann et al. (1999), this species is widespread in the region and was likely just underestimated in the study area; *Pyrgus armoricanus* – A common and widespread species in lowlands, but rare in the Aosta Valley (Hellmann et al. 1999). A single specimen was collected at the southernmost edge of the study area on 14 August 2023, with identification confirmed by genitalia examination (at: https://www.inaturalist.org/observations/178351010); *Thecla betulae* – A rare species in the whole region, with no data from the past 20 years based on the results of Alberti et al. (2025). We observed it twice within the MANP, on 21 June 2022 and 3 September 2024 (at: https://www.inaturalist.org/observations/239592077). In the recent past, one of the authors (MB) recorded it in the MANP on 22 September 2010, and elsewhere in the region on 19 August 2006 and 10 September 2007, confirming its more regular presence in this Alpine area, leading to think that the species is probably underestimated due to its low detectability.

Topic 2 – Target species from the project COBIODIV and species of conservation concern

The COBIODIV project focused on eight diurnal butterfly species, selected for their conservation importance or because they are rare or poorly known in the Aosta Valley region:

Apatura iris – Previously known in the area from a single observation (Brockmann et al. 1993), this study reports 13 observations from seven localities, all but one outside the Natura 2000 boundaries. The species is well represented at the only site within these boundaries, at 1,630 m in the NW sector, where nectar flowers (*Cardus* sp.) are abundant in the ecotone with the priority habitat 9180* - Tilio-Acerion forests of slopes, where a maximum of eight individuals were observed feeding together on 10 August 2020; *Colias palaeno* – See Topic 1; *Euphydryas aurinia* ssp. *debilis* – The nominal form is a protected species listed in Annex II of the Habitats Directive. In the study area *E. aurinia* ssp. *debilis* occurs in the following habitats: 4,060 – alpine heath, 7,110 – raised bogs and 7,140 – transition mires. This taxon (also known as *E. glaciegenita*, Balletto et al. 2014) was previously recorded for two localities in the upper Chalamy and Champorcher valleys, and thanks to this study, its known range expanded to six additional localities. The species appears widespread in the study area and the Alps but remains localized and difficult to observe because its phenology varies across valleys. Adults seem to be active only a few days at each site, flying between late June and mid-August (at higher altitudes or north-facing slopes), showing an earlier flight period than reported in the Gran Paradiso National Park by Casacci et al. (2015). Despite this, *E. a. debilis* is classified as of Least Concern due to its wide distribution and absence of direct threats; *Parnassius apollo* – This protected species is listed in Annex IV of the Habitats Directive. It can reach high local densities, as observed in the W sector, with 41 individuals recorded along a one km transect at 2,200 m on 6 August 2021. The species is widespread between 1,055 and 2,528 m and does not face direct threats. However, CITES Appendix II (CITES 2025) states: *Although not currently at risk of extinction, the species may become so without trade controls*; *Parnassius phoebus* – Confirmed in the MANP only after Pensati (2007–2008), this species is now known abundant and widespread within its habitat, with 73 observations from 29 localities between 1,500 and 3,000 m. Notably, a small stream plain with a north exposure at the lowest altitude (outside Natura 2000) is home to the species, which is active from mid-June but not in July, unlike other sites where it persists until the end of August; *Phengaris arion* – A protected species (Habitats Directive, Annex IV), widespread across the Alps and not facing direct threats in this biogeographic region. In our study area, we recorded 53 observations from 21 localities, ranging from 1,100 to 2,419 m. However, significant densities were never observed, with a maximum of four individuals at any site; *Phengaris alcon* ssp. *rebeli* – This species, referred to as *P. alcon,* had not been observed since 1992 (Brockmann et al. 1993), and was listed as of interest for more recent confirmation and because it is threatened similarly to other European species of *Phengaris* in Europe (Maes et al. 2019; Kajzer-Bonk & Nowicki 2022). Although not protected, it is rarer than *P. arion*, with only 15 records from nine localities, typically with one or two individuals per site. Notably, it was not found every year at known sites. The *P. alcon* complex, which includes various ecotypes across Europe, is debated, with the *rebeli* ecotype being the only taxon reported here. While not considered a valid species by some authors (Wiemers et al. 2018), recent genomic studies (Lucek et al. 2024) recommend recognizing it as a distinct species. In the study area, *P. alcon ssp. rebeli* co-occurs with *P. arion* at least at five sites, suggesting that management actions for *P. arion* should also benefit it; *Zerynthia polyxena* – A protected species (Habitats

Directive, Annex IV), previously considered very rare in the region (Hellmann et al. 1999), and therefore targeted for standardized data collection. The COBIODIV project helped to confirm a broader distribution than expected, with high local densities in some areas. Notably, 24 adults were observed along a 400 m transect on 16 April 2022. However, all known sites are outside protected areas or the Natura 2000 network, highlighting the need to establish or expand protected sites to include populations of this rare and protected species (Battisti et al. 2023).

Topic 3 – Species not confirmed in recent years and other species of interest

Four species previously reported by Brockmann et al. (1993) were unconfirmed: *Carcharodus alceae* and *Iolana iolas* – These two species were previously recorded in the study area with only one and two observations, respectively, in the lower Chalamy valley (NE sector). Their occurrence at lower altitudes, combined with their *uncommon presence* as reported by Hellmann et al. (1999), likely contributed to the lack of recent confirmations; *Thymelicus acteon* – The absence of recent observations for this taxon may be linked to its occurrence at lower altitudes and, to a lesser extent, to the limited genitalia examinations of specimens identified as *T. sylvestris*. We only recorded 17 observations from 10 localities of *T. sylvestris*, with just two records from the NE sector below 1,300 m, where Brockmann et al. (1993) reported *T. acteon*. Nevertheless, targeted sampling could confirm the species in the SE and NE sectors, where it is likely present as *common and widespread at lower altitudes in the region* as described by Hellmann et al. (1999); *Melitaea aurelia* – Only one recent observation is available, but it remains doubtful, as the single specimen, recorded in early summer at a relatively low elevation (1,300 m), was not examined for genital structures. Moreover, no other individuals have raised sufficient taxonomic uncertainty to warrant genitalia examination. As with the previously discussed species, it is possible that the limited sampling effort early in the season, at relatively low elevations, was insufficient to confirm the species reported by Brockmann et al. (1993).

We also highlight *Oeneis glacialis*, a species generally considered uncommon, possibly due to its preference for rocky habitats and cliffs, or its biennial life cycle, which may cause it to be absent in alternate years. Notably, all our observations with 16 records from 11 localities were in even years (2020 and 2024).

Erebia medusa and *E. meolans* are recorded only in the SE sector and represent a small fraction of the total data. *E. medusa* is restricted to the Fer Creek, with no more than 10 individuals observed at the same localities on 29 June and 14 July 2021, making this the only confirmed site for the species in the region over the past 50 years (Hellmann et al. 1999). *E. meolans,* instead, is known from a single observation at Brenve Creek (at: https://www.inaturalist.org/observations/123229856), and is generally rare in the region, with just one historical record for the SE sector in the study area and only one recent observation elsewhere by one author (AB) (at: https://www.inaturalist.org/observations/124587186).

In conclusion, we address the complex *Leptidea sinapis*, where the presence of *L. juvernica* cannot be ruled out, given that identification requires genetic analysis (Dincă et al. 2013), despite suggested differences in trophic niches (Gallo et al. 2015). Ongoing research continues to uncover new taxonomic distinctions across southern Europe (Nazari et al. 2023), including cases of sympatry in mountain regions (Solovyev et al. 2015). For now, we can only confirm the presence of this species complex in the area.

Conclusions / Highlights

We updated the list of diurnal butterflies (Papilionoidea) occurring in the enlarged Special Protected Area *Mont Avic and Mont Emilius* to 146 taxa (50% of the Italian butterfly fauna);

We highlight the notable percentage of endemic or ecologically significant mountain species, emphasizing how this area could be considered a hotspot for butterflies in Europe;

We provide a detailed discussion on 28 taxa of particular interest, along with distribution, abundance and ecology for all taxa.

Data availability

All data are archived at the offices of the Mont Avic Natural Park Management Authority and may be consulted or used upon request, provided that such use aligns with the Authority's ethical guidelines and receives prior authorization (for further details: https://montavic.it/#contatti).

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Authors

Andrea Battisti

is a field biologist and naturalist who specialises in birds and diurnal butterflies, with a particular focus on Italian species of conservation concern. His work covers the broader biodiversity of north-western Italy and its associated habitats, including studies on Odonata and Orthoptera.

Daniele Stellin

has a degree in Natural Sciences and specialises in Freshwater Ecology. He is the author and co-author of numerous scientific and technical articles on the protection and management of Alpine freshwater ecosystems. He is currently the director of the Mont Avic Natural Park in the Aosta Valley.

Massimo Bocca

has a degree in agronomic sciences and wrote his thesis on entomology. Former Director of the Mont Avic Natural Park and the Natural History Museum of the Aosta Valley. He is the author of over 50 scientific papers on zoology, particularly ornithology.

Table 1 – Checklist of species and their associated information within the study area. Nomenclature follows Wiemers et al. (2018), with subspecies nomenclature as taxa by Balletto et al. (2014) if deemed appropriate. Table details:
i) Sector codes correspond to cardinal directions (W = West, NW = North-West, N = North, NE = North-East, SE = South-East), as shown in Figure 1;
ii) Altitudinal range is rounded to the nearest 10 meters. Maximum altitude is highlighted in bold if above 3,000 m and the lowest or highest altitude from a single observation is given in brackets. When the altitudinal limit was not confirmed by the original data of the present work, the reference literature is cited in lowercase brackets as (A) = Brockmann et al. (1993), or (B) = Pensati (2007–2008);
iii) Abundance estimation based on recent years: 'Abundant'=more than 100 individuals/year, occurring in more than 20 localities; 'Common'=more than 10 individuals/year in over 10 localities; 'Rare'=less than five individuals/year, observed in less than 10 localities at all; 'Very Rare'=less than three individuals ever recorded; 'Biblio'=literature data only;
iv) Occurrence in Natura 2000 sites is marked as 'x' if the species has been recorded within the boundaries, or as 'Pr' if highly probable due to habitat availability and nearby occurrences;
v) Ecological preferences categorized by temperature (eurythermal, microthermal, mesothermal, thermophilous) and ground humidity (eurychorous, hygrophilous, mesophilous, xerophilous) following Balletto & Kudrna (1985);
vi) Species endemic to the mountains of Southern Europe are marked as 'A'=Alpine, or 'A+'=if their distribution includes the Alps and one other mountain range among the Apennines, Pyrenees or Dinaric Alps;
vii) IUCN Red List categories are reported for Italy and Europe as Endangered (EN), Vulnerable (VU), Near Threatened (NT), or Not Evaluated (NE).
For completeness, previously reported nomenclature (Brockmann et al. 1993; Pensati 2007-2008) follows: Aglais io (previously treated as Inachis io), Agriades sp. (formerly Vaccinina sp. or Albulina sp.), Boloria sp. (prev. Clossiana sp.), Erebia arvernensis (prev. E. carmenta), Euphydryas cynthia (prev. Hypodryas cynthia), Euphydryas aurinia ssp. debilis (listed as Eurodryas a. or E. glaciegenita), Phengaris sp. (prev. Maculinea sp.), Plebejus sp. (prev. as Lycaeides sp.), Melitaea sp. (prev. Mellicta sp.), M. celadussa (mistaken for M. athalia or M. nevadensis), Ochlodes sylvanus (prev. as O. venatus), Polyommatus sp. (listed as Agrodiaetus sp. or Plebicula sp.), Pontia edusa (mistaken for P. daplidice), Speyeria aglaja (listed as Argynnis a. or Mesoacidalia a.) and Vanessa cardui (prev. as Cynthia c.).

Taxon	Distribution	Altitudinal Range [m]	Abundance estimation	IT1202000 - Mont Avic& Mont Emilius	IT1202020 - Mont Avic Natural Park (boundaries 2023)	IT1206054 - Vallone del Grauson	IT1205065 - Vallone dell'Urtier	IT1205100 - Vallée de l'Alleigne	Ecology (thermal & humidity preferences)	Endemism	Italian Red List	IUCN Red List
PAPILIONIDAE												
Papilioninae												
Iphiclides podalirius (Linnaeus, 1758)	NW–NE–SE	500–2,550	Rare	x	x	-	-	-	Thermophilous; Mesophilous			
Papilio machaon Linnaeus, 1758	whole area	500–2,225	Common	x	x	x	x	-	Thermophilous; Mesophilous			
Parnassiinae												
Parnassius phebus (Fabricius, 1793)	W–NW–N–SE	1,510–3,010	Common	x	x	x	x	x	Thermophilous; Hygrophilous			NT
Parnassius apollo (Linnaeus, 1758)	whole area	1,050–2,530	Abundant	x	x	x	x	x	Mesotherma; Xerophilous			NT
Zerynthia polyxena ([Denis & Schiffermüller], 1775)	NE–SE	640–1,460	Common	-	-	-	-	-	Mesothermal; Mesophilous			
HESPERIIDAE												
Heteropterinae												
Carterocephalus palaemon (Pallas, 1771)	N–NE–SE	1,280–1,970	Rare	x	x	-	-	-	Mesothermal; Mesophilous			
Hesperiinae												
Ochlodes sylvanus (Esper, 1777)	NW–N–NE–SE	700–1,890	Common	x	x	-	-	-	Mesothermal; Mesophilous			
Hesperia comma (Linnaeus, 1758)	whole area	1,290–2,590	Abundant	x	x	x	x	x	Thermophilous; Mesophilous			
Thymelicus acteon (Rottemburg, 1775)	$NE_{(A)}$	520–1,310	(Biblio)	-	-	-	-	-	Thermophilous; Mesophilous			NT
Thymelicus sylvestris (Poda, 1761)	whole area	720–2,130	Common	x	x	-	x	-	Thermophilous; Mesophilous			
Thymelicus lineola (Ochsenheimer, 1808)	whole area	1,260–2,380	Common	x	x	Pr	x	Pr	Mesothermal; Mesophilous			
Pyrginae												
Spialia sertorius (Hoffmansegg, 1804)	whole area	1,290–2,320	Rare	x	x	x	-	-	Mesothermal; Mesophilous			
Carcharodus alceae (Esper, 1780)	$NE_{(A)}$	500	(Biblio)	-	-	-	-	-	Mesothermal; Mesophilous			
Carcharodus lavatherae (Esper, 1783)	$N–NE_{(A)}$	$450_{(A)}$–1,530	Rare	-	-	-	-	-	Thermophilous; Xerophilous			NT
Carcharodus floccifera (Zeller, 1847)	$W–N–NE_{(A)}$	$1,250_{(A)}$–2,340	Rare	x	Pr	Pr	x	-	Eurythermal; Eurychoros			NT
Erynnis tages (Linnaeus, 1758)	W–N–NE–SE	730–2,310	Common	x	x	Pr	Pr	Pr	Eurythermal; Mesophilous			
Pyrgus malvoides (Elwes & Edwards, 1897)	whole area	$500_{(A)}$–$2,640_{(B)}$	Common	x	x	Pr	x	Pr	Mesothermal; Mesophilous			
Pyrgus carthami (Hübner, [1813])	W–N–NE–SE	$450_{(A)}$–2,280	Common	x	x	x	Pr	-	Thermophilous; Mesophilous			
Pyrgus cacaliae (Rambur, 1839)	N	2,490	Very Rare	x	-	-	-	-	Mesothermal; Mesophilous	A		
Pyrgus alveus (Hübner, [1803])	$NE_{(A)}$–$SE_{(B)}$	$1,550_{(A)}$–$2,690_{(B)}$	Rare	x	x	-	-	-	Mesothermal; Xerophilous			
Pyrgus andromedae (Wallangren, 1853)	$N–NE_{(A)}$–SE	1,490–2,310	Rare	x	x	-	-	x	Eurythermal; Mesophilous			

Pyrgus armoricanus (Oberthür, 1910)	SE	540	Very Rare	-	-	-	-	-	Thermophilous; Mesophilous			
Pyrgus carlinae (Rambur, [1839])	whole area	1,520–2,620	Common	x	x	x	x	Pr	Mesothermal; Xerophilous	A		
PIERIDAE												
Dismorphiinae												
Complex Leptidea sinapis (Linnaeus, 1758)	whole area	520–1,880	Common	x	x	-	-	x	Mesothermal; Mesophilous			
Coliadinae												
Gonepteryx rhamni (Linnaeus, 1758)	whole area	$500_{(A)}$–$2,330_{(B)}$	Common	x	x	-	-	Pr	Mesothermal; Mesophilous			
Colias alfacariensis Ribbe, 1905	W–NW–$NE_{(A)}$–SE	$1,300_{(A)}$–2,500	Common	x	x	x	x	-	Thermophilous; Mesophilous			
Colias phicomone (Esper, [1780])	whole area	$1,720$–$2,850_{(B)}$	Abundant	x	x	x	x	Pr	Mesothermal; Xerophilous			NT
Colias crocea (Geoffroy, 1785)	W–N–NE–SE	730–2,800	Common	x	x	x	Pr	Pr	Thermophilous; Mesophilous			
Colias palaeno (Linnaeus, [1760])	NW–N–NE–SE	(1,620) 2,050–2,470	Rare	x	x	-	-	Pr	Mesothermal; Hygrophilous			
Pierinae												
Aporia crataegi (Linnaeus, 1758)	whole area	$500_{(A)}$–2,520	Abundant	x	x	x	x	Pr	Mesothermal; Mesophilous			
Pontia callidice (Hübner, [1800])	whole area	2,000–3,559	Common	x	x	Pr	Pr	Pr	Microthermal; Xerophilous			
Pontia edusa (Fabricius, 1777)	NE	500–1,530	Rare	x	x	-	-	-	Thermophilous; Xerophilous			
Pieris brassicae (Linnaeus, 1758)	N–NE–SE	500–$2,330_{(B)}$	Rare	x	x	-	-	-	Mesophilous			
Pieris rapae (Linnaeus, 1758)	SE	500–2,820	Common	x	x	Pr	x	Pr	Eurythermal; Mesophilous			
Pieris mannii (Mayer, 1851)	NE	$500_{(A)}$–730 (1,300)	Rare	-	-	-	-	-	Thermophilous; Xerophilous			
Pieris bryoniae (Hübner, [1806])	whole area	($500_{(A)}$) 1,430–2,350	Abundant	x	x	Pr	Pr	Pr	Microthermal; Mesophilous			
Pieris napi (Linnaeus, 1758)	whole area	500–1,940 (2,160)	Common	x	x	Pr	Pr	x	Mesothermal; Mesophilous			
Euchloe simplonia (Freyer, 1829)	$NW–N–NE–SE_{(B)}$	(1,400) 1,900–2,300	Rare	x	x	-	-	-	Mesothermal; Xerophilous	A+		
Anthocharis cardamines (Linnaeus, 1758)	N–NE–SE	500–$2,230_{(B)}$	Common	x	x	-	-	Pr	Mesothermal; Mesophilous			
RIODINIDAE												
Nemeobiinae												
Hamearis lucina (Linnaeus, 1758)	W–N–NE–SE	500–1,510	Rare	x	x	-	-	-	Mesothermal; Mesophilous			
LYCAENIDAE												
Lycaeninae												
Lycaena alciphron (Rottemburg, 1775)	W–NW–N–NE	500–1,870	Common	x	x	Pr	Pr	-	Mesothermal; Xerophilous			
Lycaena hippothoe ssp. *eurydame* (Hoffmansegg, 1806)	whole area	$1,100_{(A)}$–2,640	Common	x	x	x	x	Pr	Mesothermal; Mesophilous	A		
Lycaena phlaeas (Linnaeus, [1760])	NE–SE	500–1,560	Common	x	x	-	-	-	Thermophilous; Eurychorous			
Lycaena virgaureae (Linnaeus, 1758)	whole area	1,000–2,300	Common	x	x	x	Pr	x	Mesothermal; Mesophilous			
Lycaena tityrus (Poda, 1761)	NE	$500_{(A)}$	(Biblio)	-	-	-	-	-	Mesothermal; Mesophilous			
Lycaena tityrus ssp. *subalpina* (Speyer, 1851)	W–N–NE–SE	1,290–2,310	Common	x	x	x	Pr	Pr	Mesothermal; Mesophilous	A		
Theclinae												
Thecla betulae (Linnaeus, 1758)	NE	1,550	Very Rare	x	x	-	-	-	Mesothermal; Mesophilous			
Favonius quercus (Linnaeus, 1758)	$NE_{(A)}$	$500_{(A)}$	(Biblio)	-	-	-	-	-	Thermophilous; Mesophilous			
Callophrys rubi (Linnaeus, 1758)	N–NE–SE	610–2,230	Common	x	x	-	-	Pr	Eurythermal; Mesophilous			
Satyrium ilicis (Esper, 1779)	NE	500–1,350	Very Rare	-	-	-	-	-	Thermophilous; Mesophilous			
Satyrium spini ([Denis & Schiffermüller], 1775)	NW–N	1,280–2,350	Rare	x	-	-	-	-	Mesothermal; Mesophilous			
Plolyommatinae												
Celastrina argiolus (Linnaeus, 1758)	NE–SE	725–1,300	Rare	-	-	-	-	-	Mesothermal; Mesophilous			
Phengaris alcon ssp. *rebeli* (Hirschke, 1905)	NW–N–NE–SE	$1,100_{(A)}$-2,350	Rare	x	x	-	-	-	Thermophilous; Hygrophilous			
Phengaris arion (Linnaeus, 1758)	W–N–NE–SE	1,100–2,420	Common	x	x	x	x	Pr	Thermophilous; Xerophilous			EN
Scolitantides orion (Pallas, 1771)	NE–SE	500–1,310	Rare	x	-	-	-	-	Thermophilous; Xerophilous			
Iolana iolas (Ochsenheimer, 1816)	$NE_{(A)}$	500–1,250	(Biblio)	-	-	-	-	-	Thermophilous; Xerophilous		NT	NT
Glaucopsyche alexis (Poda, 1761)	N–NE–SE	500–1,680	Rare	-	-	-	-	-	Mesothermal; Mesophilous			
Cupido osiris (Meigen, 1829)	W–NE	1,500–2,333	Rare	x	-	-	x	-	Mesothermal; Mesophilous			
Cupido minimus (Fuessly, 1775)	whole area	($500_{(A)}$) 1,500–2,620	Abundant	x	x	x	x	Pr	Thermophilous; Xerophilous			
Plebejus argus (Linnaeus, 1758)	W–N–NE–SE	1,250–2,360	Common	x	x	-	-	Pr	Mesothermal; Mesophilous			
Plebejus idas (Linnaeus, [1760])	whole area	1,500–2,530	Abundant	x	x	x	x	Pr	Mesothermal; Mesophilous			
Agriades orbitulus (Prunner, 1798)	whole area	1,800–2,810	Rare	x	x	x	x	-	Microthermal; Xerophilous			
Agriades optilete (Knoch, 1781)	NW–N–NE	1,550–2,370	Rare	x	x	-	-	-	Microthermal; Hygrophilous			
Agriades glandon (Prunner, 1798)	whole area	2,023–2,720	Common	x	x	x	x	Pr	Microthermal; Hygrophilous			
Eumedonia eumedon (Esper, 1780]	NW–N–NE–SE	($1,100_{(A)}$) 1,700–2,310	Common	x	x	-	-	Pr	Mesothermal; Mesophilous			
Kretania trappi (Verity, 1927)	W–N	1,510–1,860	Rare	x	-	Pr	Pr	-	Thermophilous; Xerophilous	A	VU	NT
Cyaniris semiargus (Rottemburg, 1775)	whole area	($500_{(A)}$) 1,100–2,700 (3,010)	Abundant	x	x	x	x	x	Mesothermal; Mesophilous			
Aricia nicias (Meigen, 1829)	whole area	1,550–2,400	Common	x	x	x	x	-	Microthermal; Mesophilous			
Aricia artaxerses ssp. *allous* (Geyer, [1837])	whole area	1,470–2,400	Common	x	x	x	x	x	Mesothermal; Mesophilous			
Aricia agestis ([Denis & Schiffermüller], 1775)	NE–SE	1,150–1,550	Rare	x	x	-	-	-	Mesothermal; Mesophilous			

Lysandra bellargus (Rottemburg, 1775)	W–N–NE–SE	$450_{(A)}$–2,190 ($2,550_{(B)}$)	Common	x	x	Pr	Pr	-	Thermophilous; Xerophilous			
Lysandra coridon (Poda, 1761)	whole area	1,100–2,600	Abundant	x	x	x	x	x	Thermophilous; Xerophilous			
Polyommatus escheri (Hübner, [1823])	W–N–NE	1,500–2,380	Rare	x	-	Pr	Pr	-	Thermophilous; Mesophilous			
Polyommatus thersites (Cantener, 1835)	N–NE	1,060–1,500 ($1,800_{(A)}$)	Rare	-	-	-	-	-	Thermophilous; Xerophilous			
Polyommatus daphnis ([Denis & Schiffermüller], 1775)	NW	1,130	Very Rare	-	-	-	-	-	Thermophilous; Xerophilous			
Polyommatus dorylas ([Denis & Schiffermüller], 1775)	whole area	1,050–2,570	Common	x	x	x	x	x	Thermophilous; Xerophilous			NT
Polyommatus icarus (Rottemburg, 1775)	N–NE–SE	450–2,000	Common	x	x	-	-	Pr	Eurythermal; Eurichorous			
Polyommatus eros (Ochsenheimer, 1808)	W–N–NE–SE	1,860–2,700	Common	x	x	x	x	-	Mesothermal; Mesophilous			NT
Polyommatus damon ([Denis & Schiffermüller],1775)	whole area	1,510–2,400	Abundant	x	x	x	x	Pr	Thermophilous; Xerophilous			NT
NYMPHALIDAE												
Limenitidinae												
Neptis rivularis (Scopoli, 1763)	NE	< 500	Very Rare	-	-	-	-	-	Mesothermal; Mesophilous			
Limenitis reducta Staudinger, 1901	N–NE	510–1,350	Rare	-	-	-	-	-	Mesothermal; Mesophilous			
Limenitis populi (Linnaeus, 1758)	N–NE	1,060–1,170	Rare	-	-	-	-	-	Mesothermal; Mesophilous			
Heliconiinae												
Issoria lathonia (Linnaeus, 1758)	whole area	500–2,520	Abundant	x	x	x	x	Pr	Termophilous; Mesophilous			
Brenthis hecate ([Denis & Schiffermüller], 1775)	NE	730	Very Rare	-	-	-	-	-	Mesothermal; Mesophilous			
Brenthis ino (Rottemburg, 1775)	NW–N–NE	1,300–1,900	Rare	x	Pr	-	-	-	Mesothermal; Hygrophilous			
Brenthis daphne ([Denis & Schiffermüller], 1775)	NW–N–NE	500–1,650	Rare	x	Pr	-	-	-	Mesothermal; Mesophilous			
Argynnis paphia (Linnaeus, 1758)	NW–N–NE	500–1,790	Common	x	x	-	-	-	Mesothermal; Mesophilous			
Speyeria aglaja (Linnaeus, 1758)	whole area	1,070–2,500	Abundant	x	x	x	x	x	Mesothermal; Mesophilous			
Fabriciana niobe (Linnaeus, 1758)	whole area	($1,100_{(A)}$) 1,300–$2,730_{(B)}$	Abundant	x	x	x	x	x	Mesothermal; Mesophilous			
Fabriciana adippe ([Denis & Schiffermüller], 1775)	NW–NE–SE	1,120–2,420	Rare	x	x	-	-	Pr	Mesothermal; Mesophilous			
Boloria pales ([Denis & Schiffermüller],1775)	whole area	($1,550_{(A)}$) 2,130–3,010	Rare	x	x	Pr	x	Pr	Mesothermal; Xerophilous			
Boloria napaea (Hoffmansegg, 1804)	whole area	1,950–2,880	Abundant	x	x	x	x	Pr	Mesothermal; Hygrophilous			
Boloria euphrosyne (Linnaeus, 1758)	whole area	($1,100_{(A)}$) 1,300–2,310	Abundant	x	x	x	Pr	Pr	Mesothermal; Mesophilous			
Boloria titania (Esper, [1793])	whole area	1,290–2,300	Common	x	x	Pr	Pr	Pr	Mesothermal; Hygrophilous			NT
Apaturinae												
Apatura iris (Linnaeus, 1758)	NW–N–$NE_{(A)}$–SE	820–1,680	Common	x	-	-	-	Pr	Mesothermal; Mesophilous			
Apatura ilia ([Denis & Schiffermüller], 1775)	NE	< 500	Very Rare	-	-	-	-	-	Mesothermal; Mesophilous			
Nymphalinae												
Vanessa cardui (Linnaeus, 1758)	whole area	500–3,010	Common	x	x	Pr	Pr	Pr	Mesothermal; Euricora			
Vanessa atalanta (Linnaeus, 1758)	whole area	500–2,590	Common	x	x	x	Pr	Pr	Mesothermal; Mesophilous			
Aglais io (Linnaeus, 1758)	$NE_{(A)}$–SE	$500_{(A)}$–2,680	Rare	x	x	-	-	-	Ubiquitous			
Aglais urticae (Linnaeus, 1758)	whole area	500–3,180	Abundant	x	x	x	x	x	Ubiquitous			
Polygonia c-album (Linnaeus, 1758)	NW–N–NE–SE	500–1,730 (2,030)	Common	x	x	-	-	Pr	Mesothermal; Mesophilous			
Nymphalis polychloros (Linnaeus, 1758)	NE–SE	520–1,310	Rare	-	-	-	-	-	Mesothermal; Mesophilous			
Nymphalis antiopa (Linnaeus, 1758)	NW–N–NE–SE	500–2,290	Rare	x	x	-	-	Pr	Mesothermal; Mesophilous			
Euphydryas aurinia (Rottemburg, 1775) ssp. *debilis* (Oberthür, 1909)	whole area	1,970–2,710	Common	x	x	x	x	Pr	Mesothermal; Mesophilous	A+		
Euphydryas cynthia ([Denis & Schiffermüller], 1775)	whole area	(1,550) 2,260–$2,710_{(B)}$	Common	x	x	x	Pr	Pr	Mesothermal; Xerophilous	A+		
Melitaea didyma (Esper, 1778)	W–N–NE–SE	500–2,190	Common	x	x	x	x	-	Thermophilous; Mesophilous			
Melitaea phoebe ([Denis & Schiffermüller],1775)	whole area	500–2,390	Common	x	x	x	x	x	Thermophilous; Mesophilous			
Melitaea cinxia (Linnaeus, 1758)	W–N–NE–SE	$500_{(A)}$–2,350	Common	x	x	Pr	x	Pr	Thermophilous; Mesophilous			
Melitaea diamina (Lang, 1789)	NW–N–NE–SE	($1,100_{(A)}$) 1,520–2,280	Rare	x	x	x	x	Pr	Mesothermal; Hygrophilous			
Melitaea celadussa Fruhstorfer, 1910	whole area	500–2,300	Abundant	x	x	x	x	x	Mesothermal; Mesophilous			
Melitaea deione (Geyer, [1832])	NE	1,000–1,550	Rare	x	x	-	-	-	Thermophilous; Mesophilous			
Melitaea varia Herrich-Schäffer, 1851	whole area	1,500–2,510	Common	x	x	x	x	Pr	Mesothermal; Mesophilous	A+		
Melitaea aurelia Nickerl, 1850	$NE_{(A)}$	1,100–1,500	(Biblio)	-	-	-	-	-	Mesothermal; Mesophilous			NT
Libytheinae												
Libythea celtis (Laicharting, 1782)	NE	510–530	Very Rare	-	-	-	-	-	Mesothermal; Mesophilous			
Satyrinae												
Coenonympha pamphilus (Linnaeus, 1758)	whole area	500–1,930	Common	x	x	-	-	Pr	Eurythermal; Euricora			
Coenonympha gardetta (Prunner, 1798)	whole area	(1,420) 1,710–2,780	Abundant	x	x	x	x	x	Mesothermal; Mesophilous	A+		
Coenonympha gardetta ssp. *darwiniana* Staudinger, 1871	NE–SE	1,890–2,180	Rare	x	x	-	-	-	Mesothermal; Mesophilous	A		
Coenonympha arcania (Linnaeus, [1760])	NW–N–NE–SE	520–1,840 ($2,060_{(B)}$)	Abundant	x	x	-	-	Pr	Mesothermal; Mesophilous			

Pararge aegeria (Linnaeus, 1758)	N–NE–SE	520–1,750	Common	x	x	-	-	Pr	Mesothermal; Mesophilous			
Lasiommata maera (Linnaeus, 1758)	whole area	500–2,130	Abundant	x	x	x	x	x	Mesothermal; Mesophilous			
Lasiommata petropolitana (Fabricius, 1787)	whole area	(1,100$_{(A)}$) 1,350–2,010	Common	x	x	Pr	Pr	x	Mesothermal; Mesophilous			
Lasiommata megera (Linnaeus, 1767)	NE–SE	500–1,530	Common	x	x	-	-	Pr	Eurythermal; Xerophilous			
Melanargia galathea (Linnaeus, 1758)	whole area	520–2,150	Abundant	x	x	x	x	x	Mesothermal; Mesophilous			
Hipparchia fagi (Scopoli, 1763)	NW–N–NE–SE	(500$_{(A)}$) 1,070–1,520	Common	x	x	-	-	Pr	Mesothermal; Mesophilous			NT
Hipparchia semele (Linnaeus, 1758)	W–NW–N–NE	1,140–2,010	Rare	x	x	Pr	Pr	-	Thermophilous; Mesophilous			
Brintesia circe (Fabricius, 1775)	NE	500–1,780	Rare	x	x	-	-	-	Mesothermal; Xerophilous			
Oeneis glacialis (Moll, 1785)	NW–N–NE–SE	1,500–2,650	Com-mon[15]	x	x	-	-	Pr	Mesothermal; Xerophilous	A		
Satyrus ferula (Fabricius, 1793)	whole area	1,070–1,740 (2,430)	Abundant	x	x	x	x	x	Thermophilous; Xerophilous			
Hyponephele lycaon (Kühn, 1774)	whole area	1,070–2,190	Abundant	x	x	x	x	Pr	Thermophilous; Xerophilous			
Aphantopus hyperantus (Linnaeus, 1758)	NW–N–NE–SE	1,030–1,440	Rare	-	-	-	-	-	Mesothermal; Mesophilous			
Maniola jurtina (Linnaeus, 1758)	NW–N–NE	500$_{(A)}$–1,550	Common	x	x	-	-	-	Mesothermal; Mesophilous			
Erebia meolans (Prunner, 1798)	SE	1,570	Very Rare	x	-	-	-	Pr	Mesothermal; Xerophilous			
Erebia arvernensis Oberthür, 1908	whole area	1,550–3,010	Abundant	x	x	x	x	x	Mesothermal; Xerophilous	A+		
Erebia gorge (Hübner, [1804])	whole area	2,250–3,390	Rare	x	x	Pr	Pr	Pr	Mesothermal; Xerophilous			
Erebia pandrose (Borkhausen, 1788)	whole area	2,170–2,690	Common	x	x	Pr	x	Pr	Microthermal; Xerophilous			
Erebia euryale (Esper, 1805)	whole area	1,120–2,360	Abundant	x	x	Pr	x	x	Mesothermal; Mesophilous			
Erebia ligea (Linnaeus, 1758)	NW–NE–SE	990–1,620 (2,140$_{(B)}$)	Rare	x	x	-	-	x	Mesothermal; Mesophilous			
Erebia pluto (Prunner, 1798)	whole area	2,680–3,180 m	Rare	x	x	-	x	-	Microthermal; Xerophilous	A+		
Erebia mnestra (Hübner, [1804])	whole area	(1,150$_{(A)}$) 2,090–3,000	Common	x	x	x	x	Pr	Mesothermal; Mesophilous	A		
Erebia albergana (Prunner, 1798)	whole area	(1,100$_{(A)}$) 1,300–2,380	Abundant	x	x	x	x	Pr	Mesothermal; Mesophilous			
Erebia melampus (Fuessly, 1775)	NW–N–NE–SE	1,540– 2,420$_{(B)}$	Abundant	x	x	-	-	Pr	Mesothermal; Mesophilous	A		
Erebia triarius (Prunner, 1798)	N–NE–SE	730–2,340	Rare	x	x	-	-	-	Mesothermal; Mesophilous			
Erebia medusa ([Denis & Schiffermüller],1775)	SE	1,560–1,700	Rare	x	-	-	-	-	Mesothermal; Mesophilous			
Erebia aethiops (Esper, 1777)	NE–SE	1,100–1,900 (2,250$_{(B)}$)	Abundant	x	x	-	-	x	Mesothermal; Mesophilous			
Erebia epiphron (Knoch, 1783)	whole area	(1,550$_{(A)}$) 1,700–2,790	Abundant	x	x	x	x	x	Mesothermal; Mesophilous			
Erebia montana (Prunner, 1798)	whole area	1,380–2,630	Abundant	x	x	x	x	x	Mesothermal; Xerophilous	A+		

(A) Brockman et al., 1993
(B) Pensati, 2007–2009

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The main determinants influencing the spending of mountaineering in Spain's Protected Natural Areas: the significance of crowding perception

Victor Dorado & Estela I. Farías-Torbidoni

Keywords: mountaineering, spending, tourism, Protected Natural Area (PNA), emblematic mountain peaks, Spain

Abstract

Protected Natural Areas (PNAs) play a crucial role in driving rural and local development within their regions. Certain PNAs feature iconic mountain peaks that serve as major attractions for mountaineering tourism. While economic impact stands as a fundamental component within the triad of sustainable tourism, and mountaineering significantly propels economic growth in destination areas, a noteworthy gap exists in the available data concerning the impact and determinants of spending within this context. This study, conducted among mountaineering visitors in PNAs, aims to analyse the distribution of spending overall and by mountain peak and to identify the determinants influencing direct spending. The research involved a sample of 562 mountaineers who ascended five Spanish peaks during the summer of 2020. The investigation revealed an average expenditure of approximately €10.62 per mountaineer. Logistics regression identified a total of six variables influencing spending. Remarkably, the research revealed *overcrowding* as a substantial predictor of mountaineering expenditure; specifically, the perception of overcrowding correlated with decreased spending. Understanding how visitors perceive and react to crowded environments is crucial for devising strategies that foster local economies and protect the natural environment of these destinations. The study's findings are relevant to mountaineering economic management in PNAs.

Introduction

Tourism is one of the fastest growing economic sectors in the world (UNWTO 2020). This includes nature tourism, defined as *tourism whose main motivation is to carry out recreational, leisure, interpretation, knowledge or sporting activities in the natural environment* (Royal Decree 416/2014) frequently in Protected Natural Areas (PNAs). Emblematic mountain peaks are among the main attractions of these areas, drawing large numbers of mountaineering enthusiasts due to their uniqueness (Apollo & Wengel 2021; Dorado et al. 2022; Farías-Torbidoni et al. 2022a; González et al. 2021; Leung et al. 2019; Rogowski 2025).

In addition to their biodiversity conservation function, PNAs act as economic generators of rural and local development in the regions where they are located (Gupta et al. 2023; Hammer et al. 2012; Kandel et al. 2022; Leung et al. 2019; Mayer et al. 2010; Naidoo et al. 2019; Sánchez-Sánchez & Sánchez-Sánchez 2022). In this context, a significant challenge in managing PNAs is to foster sustainable tourism. Sustainable tourism is characterized by considering the comprehensive array of present and future economic, social and environmental impacts, as well as addressing the needs of the environment, the local population and visitors alike (UNWTO & UNEP 2005). Regarding economic aspects, different methodologies have been used to assess the monetary value generated through visits to PNAs. Globally, it is estimated that PNA visits generate an annual spending of approximately €543 billion (Balmford et al. 2015). In Europe, specifically in national parks, the economic impact generated by visits is €14.5 billion per year (Schägner et al. 2017).

Promoting sustainable tourism in PNAs necessitates the skilful management of a delicate balance among economic, social and environmental factors. Economic impact studies can be classified into two main groups: i) those dealing with direct spending; ii) those that examine the economic impact generated. Direct spending refers to the amount spent by non-local visitors on specific services (for example hiring guides) or products in the PNA and its surrounding area. Economic impact generated, on the other hand, is broader, defined as the net changes in the economic base of a region that can be imputed to the new money brought in by non-local visitors thanks to the very existence of the PNA and its management (Cullinane et al. 2014). Among the first group, several studies have estimated the impact of the spending of visitors to PNAs on: protection of the natural area (Carlsen & Wood 2004; Cini & Saayman 2014; Gupta et al. 2023; Job 2008; Kruger et al. 2012; Mayer et al. 2010); the activity carried out (Farías-Torbidoni & Barić 2020; Fredman 2008; Mehmetoglu 2007; Raya et al. 2017; Schirpke et al. 2018); psychosocial factors (Lima et al. 2012; Veisten et al. 2014); products related to the PNA (Knaus et al. 2017). It is worth highlighting the studies of Cini and Saayman (2014), Fredman (2008), Kruger et al. (2012), Lima et al. (2012), Mehmetoglu (2007), Raya et al. (2017), Veisten et al. (2014), Farías-Torbidoni and Barić (2020) and Seguí-Urbaneja et al. (2025) which, in addition to calculating direct visitor spending in the PNAs concerned, went a step further by identifying the determinants of this spending. Where the second group of articles is concerned (those that examine or calculate the economic impact generated), various methodologies are used, all of them with their strengths and weaknesses, which can be adapted ac-

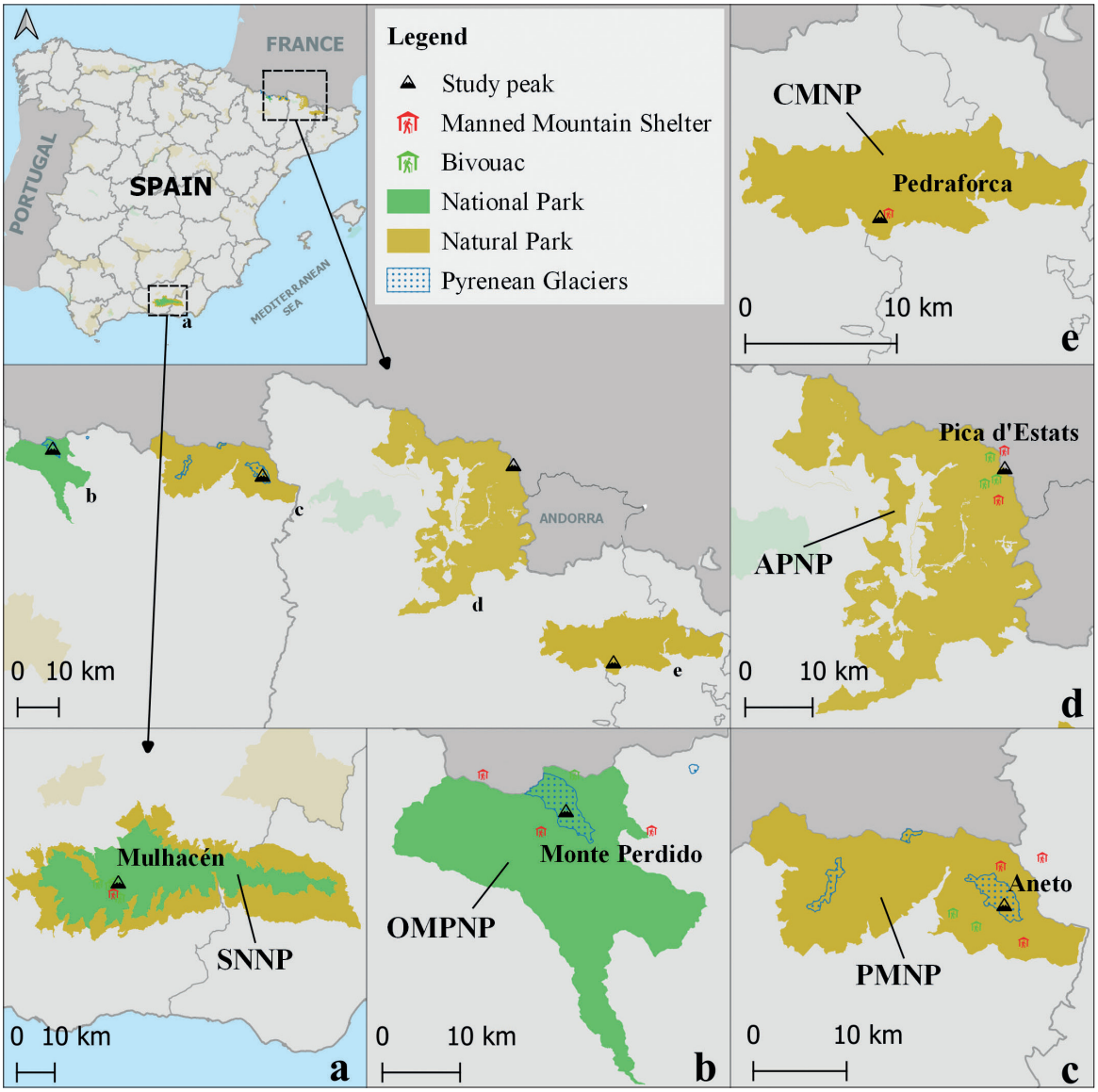


Figure 1 – Geographical location of the study peaks and their protection categories. Study Areas: a) Mulhacén: SNNP = Sierra Nevada National Park; b) Monte Perdido: OMPNP = Ordesa and Monte Perdido National Park; c) Aneto: PMNP = Posets-Maladeta Natural Park; d) Pica d'Estats: APNP = Alt Pirineu Natural Park; e) Pedraforca: CMNP = Cadí-Moixeró Natural Park.

cording to the data available in the area to be studied. Our study focused on direct spending (the first group).

At the national and international level, previous research has reported notable differences in direct visitor spending across PNAs reflecting variation in activity type, local infrastructure and environmental characteristics. For example at the national level, Raya et al. (2017) reported €20.30 for hiking-focused visitors in Berguedà, located in the pre-Pyrenean region. In the eastern Pyrenees, the Capçaleres del Ter i del Freser Natural Park recorded an average of €25.66 per visitor (Farías-Torbidoni et al. 2022b). In the Alt Pirineu Natural Park, average daily spending has been estimated at €31.70 (Farías-Torbidoni & Barić 2020), while in the Cadí-Moixeró Natural Park, located in the pre-Pyrenean region too, average spending reached €39.45 (Seguí-Urbaneja et al. 2025). In contrast, a higher average of €67.50 was found in the Ordesa and Monte Perdido National Park (Fernández et al. 2020). At the international level, the trend is similar. Schirpke et al. (2018) reported an average daily expenditure of €48.56 per visitor across 10 Natura 2000 sites in Italy, including hiking, cycling and food-related tourism. In Germany, Job et al. (2008) estimated €43.90 and €57.50 per day in the Müritz National Parks and Berchtesgaden respectively.

While most studies on visitor spending have focused on socio-demographic or trip-related variables, some authors have argued that socio-economic impact studies should go beyond purely economic measures. In this sense, Saayman and Saayman (2010) emphasized that such analyses should also consider the contribution of tourism to people's quality of life and other social dimensions, even when these are not di-

Table 1 – Main characteristics of the study peaks.

Variable		Peak				
		Mulhacén	**Monte Perdido**	**Aneto**	**Pica d'Estats**	**Pedraforca**
General characteristics						
Location[a]		30N 472300 4100841	31N 256998 4729051	31N 307853 4722508	31N 368712 4725071	31N 392983 4677231
Region		Andalucía	Aragón	Aragón	Catalunya	Catalunya
Distance form biggest cities (km)[b]		Granada: 43 Málaga: 170	Huesca: 87 Zaragoza: 158	Huesca: 152 Lleida: 162	Barcelona: 265 Lleida: 170	Barcelona: 145 Lleida: 195
Mountain shelter	Manned	1	3	3	2	1
	Bivouac (free)	4	1	2	3	0
Characteristics of management						
Protection level		Natura 2000	Natura 2000	Natura 2000	Natura 2000	Natura 2000
IUCN Management Category		II	II	V	V	V
Physical characteristics						
Altitude m asl		3,479	3,355	3,404	3,143	2,506
Number of access routes		5	3	2	3	3
Length of most popular track (km)		16.5	31.1	14.8	18.4	7.6
Positive elevation (m)		1,255	2,889	1,499	1,582	1,059
Physical particularities		Rocky ground	Glacier and Rocky ground instability	Glacier	Rocky ground	Rocky scrambling
Difficulty (Sendif scale)[c]		1,894	4,629	2,076	2,336	1,435
Access regulation		No regulation	Temporary parking regulation	Temporary parking regulation	No regulation	No regulation
Accessibility		The length of the route, the physical characteristics of the terrain and the low positive elevation make this peak the most accessible	The length of the ascent routes and the high positive elevation mean that most mountaineers have to stay overnight on the mountain in order to climb Monte Perdido; accessibility is considered to be limited	The need for crampons and ice axes to overcome the glacier and the Mahoma pass to reach the peak make Aneto the least accessible. Alternative routes require technical climbing knowledge	The physical characteristics of the routes (rocky ground) and the high positive elevation limit the access to the peak, requiring a high percentage of mountaineers to overnight in the park	Despite the high positive elevation, the shortness of the ascent routes makes this peak the second most accessible. Alternative routes make it possible to avoid the scrambling pass
Social characteristics						
Number of park visitors 2020		418,734	422,570	No data	367,713	363,370
Number of peak visitors 2020		19,609	17,002	9,912	7,713	27,678
% Mountaineering in the park		4.7	4.0	No data	2.1	7.6
Length of stay in days. Mean (SD)[d]		1.8 (1.5)	2.1 (1.0)	2.7 (3.2)	2.2 (1.7)	1.3 (0.5)

[a] *The ETRS89/UTM coordinate reference system was used.*

[b] *Google Maps was used for the calculation (distance).*

[c] *Sendif is a method to determine the difficulty of walking routes developed by the Institute for the Development and Promotion of the Alt Pirineu and Aran. It distinguishes five levels of difficulty: Very Easy (<135), corresponding to routes up to 6 km with a maximum ascent of 50 m and suitable for all users, including families and seniors; Easy (135–400), up to 13 km or 225 m ascent, appropriate for users with basic fitness; Moderate (401–860), up to 20 km or 575 m ascent, requiring average physical condition and up to four hours of walking; Demanding (861–1,200), involving ascents of around 800 m and suitable for regular mountain walkers; and Very Demanding (>1,200), corresponding to high-mountain routes exceeding 900 m ascent, suitable only for experienced hikers (IDAPA 2018).*

[d] *Number of days spent in the area of influence of the PNAs where the peak is located, usually limited to neighbouring municipalities; SD – Standard deviation.*

rectly monetizable. Following this rationale, our study incorporates perceived crowding (a subjective yet policy-relevant social factor) as a potential determinant of visitor spending. To our knowledge, this is the first study to explore this relationship in the specific context of mountaineering on high mountain peaks within PNAs.

Despite the fact that economic impact is one of the three pillars of sustainable tourism and mountaineering is a key driver of economic growth in destinations where it is practised (González et al. 2021; Leung et al. 2019), there is a lack of data on the determinants of spending in this context. To address this gap, this study focuses on five emblematic Spanish mountain peaks to examine:

i. the profile of spending and non-spending mountaineers;
ii. the distribution of spending overall and by mountain peak;
iii. the determinants of direct spending.

By doing so, we aim to gain a better understanding of the economic contributions of mountaineering and provide insights for sustainable tourism planning and management in these destinations.

Methods

Study area

The study was carried out on five mountain peaks in Spain: Mulhacén, Monte Perdido, Aneto, Pica d'Estats and Pedraforca (Figure 1).

The peaks are situated in two distinct mountain ranges: i) the Béticas range within the Sierra Nevada National Park, home to Mulhacén, the highest peak of the Iberian Peninsula; ii) the Pyrenees, housing notable peaks such as Monte Perdido in the Ordesa and Monte Perdido National Park; Aneto (the highest Pyrenean peak) protected by the Posets-Maladeta Natural Park; Pica d'Estats (Catalonia's highest peak) in the Alt Pirineu Natural Park (the region's largest); and Pedraforca in the Pre-Pyrenees within the Cadí-Moixeró Natural Park – an iconic peak in Catalonia that garnered the highest number of visits in 2020. Detailed descriptions of the main characteristics of these peaks are provided in the Table 1.

Data collection

Simple random sampling was used to select participants in our survey, choosing the first or second person in the group (>16 years old) alternately, whether male or female, who were visiting the peak. The data collection period was from 31 July 2020 to 5 September 2020, with a total of 30 fieldwork days carried out from 8:00 to 16:00. The survey took approximately 15 minutes to complete. The total sample comprised 578 visitors, of whom 562 were considered suitable (10 local visitors were excluded, and six were eliminated due to lack of data on the number of people in the group or length of stay). Finally, the margin of error for the total sample was set at ±5 calculated for a 95% confidence level (see Table 2).

Survey instrument

The survey included 37 questions structured in six dimensions. It was written in Spanish and translated into Catalan, English, French and German. Data was collected on sociodemographic characteristics (gender, age, level of education, occupation, region of residence, environmental knowledge), the visit characteristics (frequency of PNA visits, type of access, frequency of peak visit, number of visitors in group, length of stay, overnight stay in the area), sports habits (mountaineering experience; member (or not) of a mountaineering federation), expenses (accommodation, catering, shopping, services), motivations to visit (e.g. drawn by mountain peak) and perceived carrying capacity (e.g. crowding). Information on spending was asked per person per day for each of the variables and was recorded in euros.

Table 2 – Distribution of fieldwork days and valid surveys by peak.

Peak	Fieldwork	Number of valid surveys
Mulhacén	6	113
Monte Perdido	6	115
Aneto	7	109
Pica d'Estats	6	111
Pedraforca	5	114

The survey and research project received the approval of the Clinical Research Ethics Committee (CEIC) of the Catalan Sports Administration, with the number 16/CEICGC/2020. All the people who participated in the study did so voluntarily, were informed about and accepted the confidential treatment of their answers, subject to the guarantees of Organic Law 3/2018, of 5 December, on Personal Data Protection and the guarantee of digital rights.

Data analysis – structured in four steps

Step 1

In this step, the profiles of spending and non-spending visitors were assessed by analysing the distributions of variables. The resulting categorical data were then tested using the Chi-square goodness-of-fit tests and the Mann-Whitney U test. For quantitative variables, since the data did not follow a normal distribution, the non-parametric Mann-Whitney U test was applied. In addition, the effect size index was calculated using the Phi and Cramer's V test (Φ) and by Pearson's r. Interpretation of the former was based on the following criteria: $\Phi < .30$ = small effect, $\Phi \approx .50$ = medium effect, and $\Phi > .80$ high effect; interpretation of Pearson's r was based on: $r < .10$= small, $r < .30$ = medium, and $r < .50$ = large (Cárdenas & Arancibia 2014; Cohen 1988; Cohen 1992). The significance level for this procedure was set at .05. All analyses were performed using IBM SPSS Statistics, v.25.

Step 2

Step 2 was in two parts. First, the mean value of the mountaineer's individual spending (Sp) per day was estimated, based on Carlsen and Wood (2004):

$$Sp = \frac{C_i}{N_V * L_S} \quad (1)$$

where C_i is the cost of the items (accommodation, food, shopping and services); N_v is the number of visitors per group; and L_s is the length of stay or number of nights of accommodation in the region. The value for mountaineering spending (M_{sp}) is obtained by adding together the spending items ($\sum Sp$):

$$M_{sp} = \sum C_{1to4} \quad (2)$$

where C_1 is cost of accommodation (e.g. refuge, hotel); C_2 is cost of catering (food and drinks); C_3 is

Table 3 – Comparison between spenders and non-spenders. SD – Standard deviation; χ^2 – chi-squared; Φ or r – effect size. MSp – Mountaineering spending.

Variables	Total sample n = 562	Non-spenders n = 219	Spenders n = 343	Comparison
Gender (%)				χ^2 = .68, p = .411, χ = .03
Male	78.1	79.9	77.0	
Female	21.9	20.1	23.0	
Age. Mean (SD)	35.4 (11.8)	34.8 (12.1)	35.7 (11.7)	U = 39.68, z = 1.13, p =.259, r = .05
Educational level (%)				χ^2 = 2.89, p = .092, χ = .07
No university education	41.3	45.7	38.5	
University education	58.7	54.3	61.5	
Occupation (%)				χ^2 = 10.43, p < .01, χ = .14
Unemployed	6.2	7.8	5.2	
Student	16.4	21.9	12.8	
Employed	77.4	70.3	81.9	
Mountain peak (%)				χ^2 = 46.07, p < .001, χ = .29
Mulhacén	20.1	28.3	14.9	
Monte Perdido	20.5	11.0	26.5	
Aneto	19.4	11.9	24.2	
Pica d'Estats	19.8	25.6	16.0	
Pedraforca	20.3	23.3	18.4	
Visitor group size. Mean (SD)	3.8 (4.2)	3.4 (2.5)	4.0 (5.0)	U = 40.49, z = 1.61, p =.108, r = .07
Length of stay. Mean (SD)	2.0 (1.8)	1.6 (0.9)	2.3 (2.2)	U = 48.42, z = 6.31, p <.001, r =.27
Overnight stay in the area (%)				χ^2 =54.80, p < .001, χ = .31
No overnight stay	25.4	42.5	14.6	
Overnight stay	74.6	57.5	85.4	
Mountaineering experience (%)				χ^2 = .02, p= .896, χ = –.01
Non-mountaineers	17.6	17.4	17.8	
Regular mountaineers	82.4	82.6	82.2	
Perceived crowding (%)				χ^2 = 4.66, p < .05, χ = –.09
No overcrowding	67.4	62.1	70.8	
Overcrowding	32.6	37.9	29.2	

cost of shopping (local products) and C_4 is cost of services (e.g. hiring mountain guides, bus tickets).

Second, the individual mountaineer's spending attributable directly to the visit to a particular mountain peak (M_{spa}) was calculated from the visit motivation variable, extracted from the surveys, following the methodology of Farías-Torbidoni & Morera (2017). This establishes the percentage of the total expenditure made according to the value selected for the visit motivation (evaluated on a Likert scale from 1 to 5):

$$M_{spa} = M_{sp} * \%A_f \text{ (1 to 5)} \quad (3)$$

where A_f is the attribution factor; a value of 1 corresponds to a 10% attribution; 2 corresponds to a 30% attribution; 3 corresponds to a 50% attribution; 4 corresponds to a 70% attribution; and 5 corresponds to a 90% attribution. For more information on the percentage of attribution depending on the motivation for the visit, see Figure A1.

Step 3

Finally, a forward stepwise logistic regression was conducted to explore the influence of potential explanatory variables on the likelihood of mountaineers' spending money during their visit (*Y*). The potential explanatory variables, which are key to the management of public use of PNAs, were: peak (*X1*), gender (*X2*), age (*X3*), educational level (*X4*), occupation (*X5*), region of residence (*X6*), environmental knowledge (*X7*), PNA (*X8*), frequency of visit to PNA (*X9*), type of access (*X10*), whether first ascent of peak (*X11*), number of visitors per group (*X12*), length of stay (*X13*), overnight stay in the area (*X14*), mountaineering experience (*X15*), federation licence (*X16*) and perceived crowding (*X17*). At each step, variables were chosen according to their contribution to the model's coefficient of determination (R^2); the Akaike Information Criterion (*AIC*) was used to set a limit on the total number of variables included in the final model. Model effects were reported as Odds Ratios (*OR*) along with their 95% Confidence Intervals (*95% CI*). Statistical significance was assumed when $p < .05$. Statistical modelling was performed in R v4.2.2 (R Core Team, 2022) and the selection of variables was made using the MASS package (Venables & Ripley 2002).

Results

Profiles of mountaineering visitors, spenders and non-spenders

The present study comprised 562 participants distributed roughly equally among the five study peaks

Table 4 – Spending per person per day attributable directly to the visit to one of the five Spanish mountains peaks [in euros]. SD – Standard deviation. M, MP, A, PE and P – Bonferroni post hoc is statistically significant for Mulhacén (M), Monte Perdido (MP), Aneto (A), Pica d'Estats (PE) and Pedraforca (P).

Variables	Total sample n=562	Peak					Comparison
		Mulhacén n=113	Monte Perdido n=115	Aneto n=109	Pica d'Estats n= 111	Pedrafor-ca n=114	
	Mean (SD)						
Accommodation (*SD*)	6.34 (14.15)	4.56 (12.28) A	5.93 (13.80)	10.05 (16.37) M, P	8.79 (18.11)	2.59 (6.31) A	$H(4)= 16.83$, $p < .01$
Catering (*SD*)	2.32 (4.08)	1.48 (2.59) MP, A	1.96 (2.59) M, PE	3.36 (5.31) M	2.02 (4.32) MP, A	2.83 (4.68)	$H(4)= 27.28$, $p < .001$
Shopping (*SD*)	0.86 (3.58)	0.53 (2.12)	0.75 (2.99)	0.83 (3.17)	1.32 (5.78)	0.86 (2.77)	$H(4)= 4.81$, $p = .307$
Services (*SD*)	1.10 (10.38)	- MP	3.96 (21.64) M, P	1.04 (6.35)	0.46 (3.53)	- MP	$H(4)= 16.08$, $p < .01$
Total spend (*SD*)	10.62 (20.05)	6.56 (13.66) MP, A	12.60 (29.37) M	15.28 (19.31) M, PE, P	12.60 (21.03) A	6.28 (9.47) A	$H(4)= 31.01$, $p < .001$

(see Table 3). The general profile of the visitor to Spain's emblematic mountains was male (78.8%), around 35 years old, university educated (58.7%), employed (77.4%). The typical mountaineer surveyed was visiting in a group of about four people and was staying on average two days. Overall, perceived overcrowding was high (32.6%). In terms of spending, accommodation was the variable on which visitors spent the most.

Out of the 562 surveyed participants, 343 (61%) were spenders and 219 (39%) were non-spenders. Spenders and non-spenders showed similar profiles in terms of gender, average age and level of education. Non-spenders exhibited a higher proportion of students and individuals without employment in comparison to spenders. The number of visitors per group was also slightly higher for spenders compared to non-spenders. There were significant differences in the duration of the visits, which tended to be longer for the spenders. Significantly more spenders than non-spenders stayed overnight in the area. Finally, a significantly smaller proportion of spenders than non-spenders reported perceiving overcrowding.

Distribution of spending by mountain peak

The distribution of visitor spending across the five study peaks shows considerable variation, while in all peaks some mountaineers reported no spending (€0), maximum expenditures reached €247.50 in Monte Perdido, €99 in Pica d'Estats, €90 in Mulhacén, €75.60 in Aneto and €47.50 in Pedraforca (Figure 2).

On average, spending on accommodation was €6.34, which was higher than for the other variables; shopping attracted the least spending, with an average of €0.86 per person. By peak, the highest spending on accommodation was by the Aneto mountaineers (€10.05); there were statistically significant differences in spending between the Mulhacén and Pedraforca mountaineers compared to the Aneto mountaineers. The Aneto mountaineers were also the biggest spenders on catering (€3.36), with significant differences observed between them and those of Mulhacén, Monte Perdido, Aneto and Pica d'Estats. For the variable of buying local products, the Pica d'Estats mountaineers were the biggest spenders (€1.32), but no significant differences were found between mountaineers on the five peaks. In terms of services, the highest spending was €3.96, by the Monte Perdido mountaineers, with significant differences compared to the Mulhacén and Pedraforca mountaineers. The highest spenders overall were the Aneto mountaineers, with €15.28 per person per day. The lowest spenders were the Mulhacén and Pedraforca mountaineers (€6.56 and €6.28 respectively). Overall, there were statistically significant differences in total spending between the different peaks. See Table 4. (For more information on the distribution of spending by items, see Figure A2).

Determinants of direct spending on mountaineering visits

The logistic model obtained after variable selection had a moderate explanatory power ($\sigma = 1.05$, *Tjur's R2* = 0.24, *AIC* = 629.22, *BIC* = 681.20), and included: peak, occupation, number of visitors per group, length

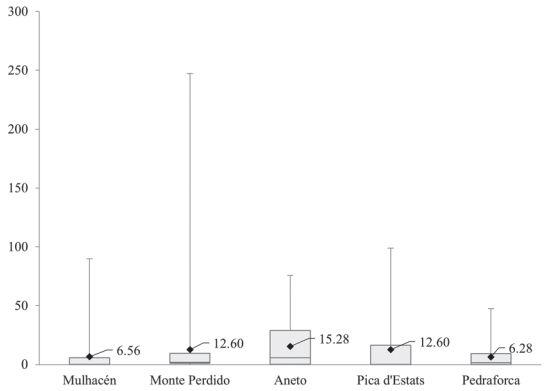


Figure 2 –Distribution of visitor spending of the study peaks. The boxplots indicate minimum, maximum, mean, median and quartiles values. Number of samples per area: Mulhacén = 113; Monte Perdido = 115; Aneto = 109; Pica d'Estats = 111; Pedraforca = 114.

Table 5 – Logistic regression analysis for potential predictors of mountaineers' spending. B – regression coefficient; Wald χ^2 – Wald test statistic; p – significance level; OR – odds ratio; CI – confidence interval for OR.

Variables	B	Wald x^2	p	OR	95% CI	
Intercept	–3.18	32.175	< .001	0.04	0.01	0.12
Peak [Monte Perdido]	1.48	19.455	< .001	4.41	2.31	8.65
Peak [Aneto]	1.25	13.952	< .001	3.49	1.83	6.81
Peak [Pica d'Estats]	–0.19	0.382	.537	0.83	0.45	1.51
Peak [Pedraforca]	1.56	20.876	< .001	4.77	2.48	9.48
Occupation [Student]	–0.06	0.015	.902	0.95	0.38	2.32
Occupation [In employment]	0.96	5.471	< .05	2.61	1.16	5.87
Visitors group size	0.10	6.932	< .01	1.11	1.03	1.20
Length of stay	0.37	9.066	< .01	1.45	1.16	1.88
First ascent peak [Yes]	0.36	2.942	.086	1.43	0.95	2.15
Overnight in the area [Overnight stay]	1.58	32.003	< .001	4.85	2.84	8.50
Perceived crowding [Overcrowding]	–0.79	12.842	< .001	0.45	0.29	0.70

of stay, overnight stay in the area and perception of crowding. The intercept in the final model corresponded to peak = *Mulhacén*, occupation = *Unemployed*, visitor group size = 0, length of stay = 0, overnight in the area = *No overnight stay*, and perception of crowding = *No overcrowding*. Model terms and effect estimates can be found in Table 5.

The choice of peak influences the chances of spending money. For example, visitors to Monte Perdido and Pedraforca were 4.41 and 4.77 times more likely respectively to spend money than visitors to Mulhacén. Visitors in employment are 2.61 times more likely than unemployed visitors to engage in spending during their visit. With each additional person in the group, the probability of spending increased by 1.11 times. Similarly, mountaineers who spent the night in the area were 4.85 times more likely to spend money than those who did not stay overnight. In addition, each day that visitors stay in the area increases the probability of spending money by 1.45 times. Finally, perceived overcrowding during the visit reduces the likelihood of spending money 0.45 times.

Discussion

In order to achieve more sustainable management of mountaineering within PNAs, detailed information is required on the economic, social and environmental impacts that the activity generates. Estimating the direct spending of mountaineering in PNAs at national scale, as in our study, provides a basis to make decisions and develop more sustainable strategies for tourism.

Our study applied a methodology based on the direct visitor spending model, which considered the proportion of spending attributed to the particular mountain peak being visited. Since no previous economic studies deal specifically with mountaineering using this same methodology at national or international level, in order to discuss our results, we draw on studies using different methodologies that have advanced the knowledge of the economic impact of mountaineering or other sports in nature.

Profiles of mountaineering visitors, spenders and non-spenders. Strategies to convert non-spenders into spenders

As previously described, spenders and non-spenders shared similar profiles in gender, average age and education level. However, non-spenders included a higher proportion of students and unemployed individuals. Group sizes were slightly larger among spenders, who also tended to stay longer and were more likely to spend the night in the area. In addition, a smaller proportion of spenders perceived overcrowding compared to non-spenders.

The presence of a substantial share of non-spenders (39% of the sample) represents both a challenge and an opportunity for enhancing the economic contribution of mountaineering. Encouraging this group to increase their expenditure could significantly reinforce local economic benefits. Our findings, together with insights from previous literature, suggest several avenues for management action. First, incentivizing larger group visits through promotions or discounts may build on the higher spending patterns observed in bigger groups, as supported by Kruger et al. (2012) and Mehmetoglu (2007). Second, promoting extended stays could foster additional spending, since longer visits have been repeatedly identified as a strong determinant of expenditure in protected areas (Fredman 2008; Seguí-Urbaneja et al. 2025). Finally, addressing perceived overcrowding emerges as a key element, whereby providing information on less crowded visiting periods or implementing visitor flow management strategies could mitigate negative perceptions and indirectly encourage spending (Weiler et al. 2019; Rogowski 2025; Luque-Gil et al. 2018).

Visitor spending and differences between peaks

The average spend per mountaineer was estimated as €10.62 per day, indicating relatively low spending compared to previous studies on other mountaineering and sport profiles in PNAs (Farías-Torbidoni et al. 2022b; Fernández et. al. 2020; Job 2008; Raya et al. 2017; Schirpke et al. 2018; Seguí-Urbaneja et al. 2025), where reported daily spending typically ranges between €20.30 and €67.50. Where the distribution of spending is concerned, as in the studies carried out by Lima et al. (2012) and Schirpke et al. (2018), we found that accommodation followed by catering were the variables on which mountaineers spent the most.

Significant differences in spending were found in relation to the different peaks, with higher spending being identified on the peaks that were less accessible (that is, where the ascent route implied a greater effort):

mountaineers on Aneto spent most during their visits (€15.28). There are two possible main explanations for these results, as demonstrated by Farías-Torbidoni & Barić (2020) for visitors to the Alt Pirineu Natural Park in Spain: (i) the direct connection between the availability of park facilities and spending; and (ii) the direct connection between levels of physical activity and visitors' spending. In our own case studies, Aneto offers more public infrastructure, providing catering and accommodation services (a mountain refuge) close to the main access to the peak. Aneto is also the most difficult climb in terms of its technical and physical requirements, followed by Monte Perdido and Pica d'Estats.

Determinants of direct spending. Managing perceived overcrowding

The findings pertaining to the determinants of expenditure align with variables such, destination, occupation, duration of stay and overnight stay in the region, consistent with prior research (Fredman 2008; Kruger et al. 2012; Mehmetoglu 2007). In particular, our results regarding duration of stay, overnight stay in the region and visitor group size are in line with those reported by Seguí-Urbaneja et al. (2025). In our case, staying overnight in the area as the highest predictor of spending among mountaineers. In addition to the obvious reasons (overnight stays may be associated with spending on accommodation), this could be because free overnight stays are prohibited or regulated in certain areas in the PNAs studied, while certain peaks require overnight stays for their ascent. However, the results for the number of visitors per group variable were contrary to the results of Kruger et al. (2012), who found that smaller groups were more likely to spend more than larger groups. It should, however, be pointed out that in our study, unlike in Cini and Saayman (2014), Fredman (2008) and Mehmetoglu (2007), gender and age were not identified as determinants of visitor spending.

In addition to these results, it is worth highlighting our finding of the non-perception of overcrowding as one of the determinants of spending by mountaineers, establishing for the first time a positive correlation between a perception of non-overcrowding of the area visited and a higher probability of spending. One potential explanation for the noteworthy finding of non-perception of overcrowding as a determinant of spending by mountaineers could be rooted in the psychological and experiential aspects of outdoor activities (Manning 2011; Apollo & Wengel 2021). Mountaineers may associate a lack of overcrowding with a more pristine and enjoyable experience, leading to a higher likelihood of spending. The positive correlation established in this study suggests that mountaineers, when perceiving the environment as less crowded, may be inclined to invest more in their overall experience, such as extended stays, additional services or higher-end equipment, contributing to increased spending patterns. This connection between the perception of non-overcrowding and spending behaviour introduces a novel dimension to our understanding of the economic dynamics in mountaineering contexts.

From a conceptual perspective, several studies have linked the perception of overcrowding to visitor satisfaction within the framework of expectation theory (Manning 2011). Our study aligns with this interpretive framework but adds a further contribution: when the experience exceeds expectations, for example, by encountering a less crowded environment than anticipated, not only does satisfaction increase, but so does the propensity to spend. This establishes a positive relationship between the perception of non-overcrowding and economic behaviour, offering a novel dimension to the analysis of public use in protected natural areas.

However, even though we know that the perception of overcrowding is a subjective phenomenon, determined by individual expectations (Berrocal et al. 2013; Luque-Gil et al. 2018; Moyle & Croy 2007) and therefore difficult to control directly, there are planning and management tools capable of modulating this perception through interventions in objective characteristics of the environment. In this sense, one of the most effective ways to indirectly influence the social perception of overcrowding is through management of the physical capacity of the area.

Based on this, a practical application that could be derived from the results would be to use this information to influence the determinants of spending. Furthermore, managing the perception of overcrowding emerges as a pivotal factor in influencing visitor spending and promoting environmental protection. By implementing strategic measures that enhance the overall tourist experience while safeguarding natural resources, destinations can not only boost their economies, but also ensure the long-term sustainability of their appeal. For instance, the following measures could be implemented to mitigate overcrowding: i) visitor quotas: establishing a limit on the number of visitors allowed per day or during peak periods can help manage crowd sizes effectively (Leung et al. 2019; González et al. 2021); ii) reservation systems: implementing an advanced reservation system for popular attractions and sites can distribute visitor arrivals evenly throughout the day and prevent sudden influxes (Miller et al. 2023; Rogowski 2025); iii) peak pricing: introducing dynamic pricing that increases during peak periods can discourage overcrowding by incentivizing visits during non-peak times (Alpízar 2006; Vásquez-Lavín et al. 2025); iv) infrastructure development: enhancing infrastructure, such as expanding parking facilities, improving transportation options and creating additional access points, can accommodate larger numbers of visitors more efficiently (Rogowski 2025); v) local engagement: involving the local community in tourism management decisions and encouraging community-based tourism initiatives can help strike a balance between

visitor numbers and the community's capacity (Apollo & Wengel 2021; Farías-Torbidoni et al. 2022a; Hammer et al. 2012; Rogowski 2025); vi) off-peak promotions: offering promotions or incentives for visiting during non-peak seasons can help distribute tourist traffic more evenly throughout the year (Lima et al. 2012; UNWTO & UNEP 2005).

Implementing a combination of these measures, tailored to the specific characteristics of each destination, can contribute to a more sustainable and enjoyable tourism experience while minimizing the negative impacts of overcrowding. This study advocates for a holistic approach that embraces responsible tourism as a catalyst for both economic prosperity and environmental well-being.

Conclusions and limitations

This study has analysed the determinants of spending of mountaineering in Spain and established the average spending per person on five emblematic mountain peaks, providing an insight into the contribution of the activity in the generation of wealth locally. The analytical methodology implemented is striking for its simplicity, which contributes to the possibility of carrying out comparable studies for other sports activities or in different environments.

Among the main findings of this study, the following stand out: i) the identification of predictors of direct spending related to socio-demographic characteristics (occupation), visitation (mountain peak, visitor group size, length of stay and overnight stay in the area) and perceptions (overcrowding); ii) a relationship between the spending generated and the level of accessibility of the peak (the lower the accessibility, the higher the spending).

The study's findings have the potential to inform strategies to maximize the economic benefits of mountain tourism for the local population while protecting the environment. In relation to the results obtained in this study generally, three recommendations could be made: i) the promotion of group visits as opposed to individual visits; ii) encouraging longer visits; iii) introducing measures to reduce the feeling of overcrowding during the recreational experience.

It is important to emphasize, however, that any action to increase the direct local economic impact should take sustainability into account. In other words, it should focus not simply on the immediate economic aspects per se, but also on environmental and social aspects. Managing the perception of overcrowding emerges as a pivotal factor in influencing visitor spending and promoting environmental protection. By implementing strategic measures that enhance the overall tourist experience while safeguarding natural resources, destinations can not only boost their economies, but also ensure the long-term sustainability of their appeal. At the same time, as suggested by Mayer et al. (2010), the implementation of measures should be accompanied by close monitoring of visitors to the PNA, in order to evaluate the area's use more broadly, as well as the economic impact of this specific form of mountain tourism.

This study, however, is not free from limitations. The analysis focuses exclusively on demand-side variables, without incorporating supply-side factors such as service availability, infrastructure quality or price structures, which may also influence spending. Future research could adopt a more comprehensive approach by integrating both visitor and destination-side variables to deepen the understanding of spending behaviour. Additionally, expanding the analysis to include other mountain-based recreational activities or other types of protected areas could help validate and extend the findings of this study.

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Authors

Víctor Dorado[1,2]

specializes in mountain tourism and visitor management in protected areas. He has seven years of experience and has led studies on visitor flows and carrying capacity. He co-founded EcoData Natura S.L.P. to promote sustainable territorial management.
https://orcid.org/0000-0002-7253-8083

Estela I. Farías-Torbidoni[1,2]

has been a professor at INEFC Lleida since 2015. She has over 20 years of experience in sports and event management in natural environments and public use in protected areas. She has coordinated over 20 applied research projects in Spain.
https://orcid.org/0000-0002-7541-8140

[1] Institut Nacional d'Educació Física de Catalunya (INEFC), centre de Lleida, Universitat de Lleida (UdL), España

[2] Grup d'Investigació Social i Educativa de l'Activitat Física i de l'Esport (GISEAFE)

Appendix

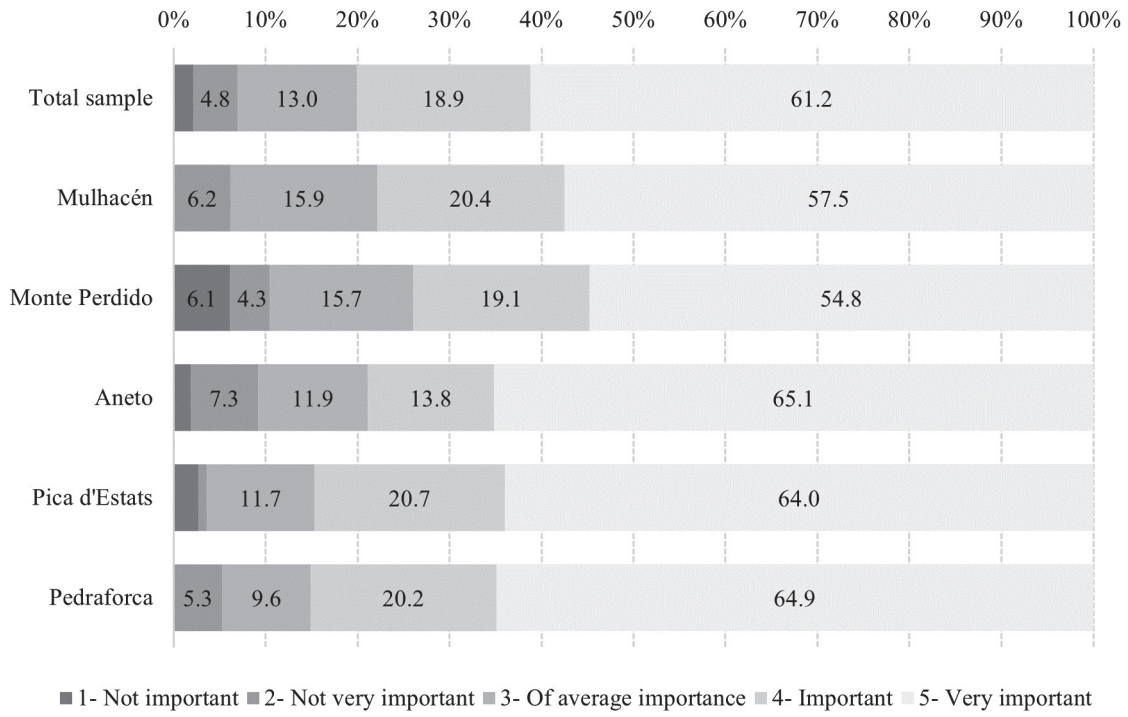


Figure A1 – Percentage of attribution depending on the motivation for the visit. In order to improve the interpretation of the graph, percentages below 2.8 have been removed.

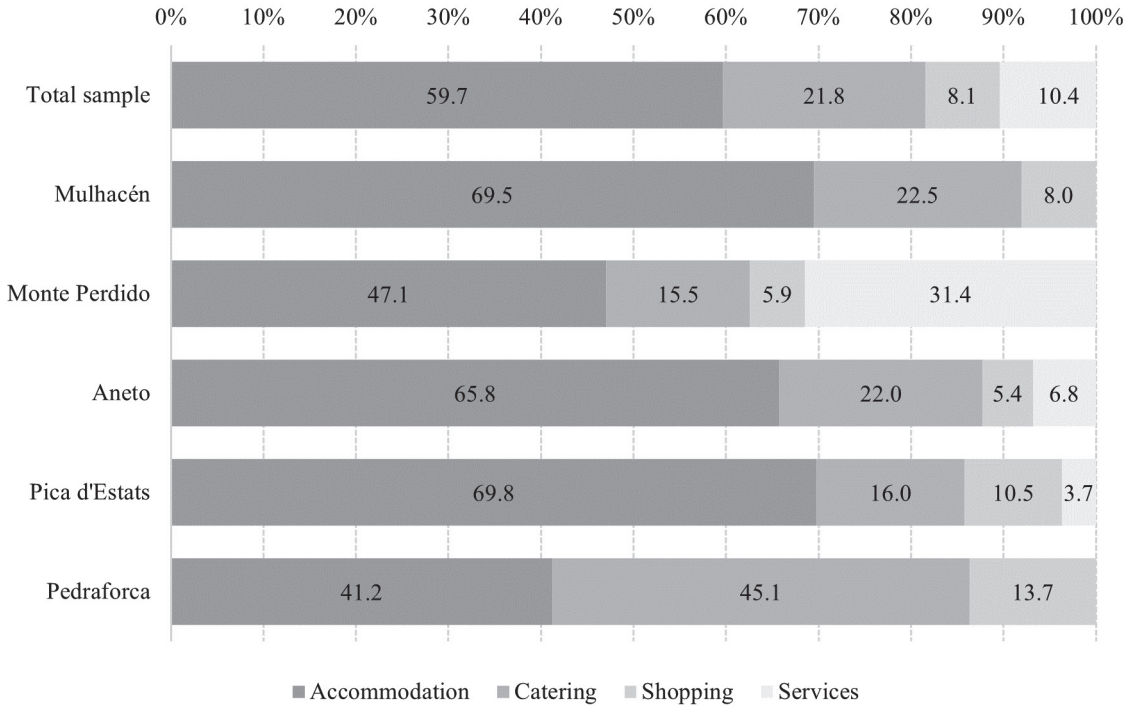


Figure A2 – Distribution of visitor spending by items per mountain peak.

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Promoting the economy while protecting nature? The UNESCO Biosphere Reserve Mont Viso as a model region for economically sustainable development in the Cottian Alps

Carlotta Sauerwein-Schlosser

Keywords: biosphere reserves, sustainable economic development, endogenous regional development, territorial governance, transnational collaboration, Cottian Alps, peripheral regions, case study, La Riserva della Biosfera transfrontaliera del Monviso / La Réserve de biosphère transfrontière du Mont Viso

Abstract

Many peripherally located Alpine regions have faced decades of depopulation and infrastructure decline. In response, protected areas (PAs) such as biosphere reserves and regional nature parks are increasingly seen as instruments to integrate nature conservation and regional development. Yet public acceptance remains limited due to concerns over potential economic restrictions. This study analyses the structural conditions shaping the actions of the UNESCO Biosphere Reserve Mont Viso in the Cottian Alps, framing PAs as strategic corporate actors by triangulating structuration theory and actor-centred institutionalism. It conceptualizes territorial agency as the capacity of PAs to initiate and sustain structural transformation. Findings show that such an agency critically depends on access to legal authority and financial resources.

Profile

Protected area

UNESCO Biosphere Reserve Mont Viso

Mountain range

Alps, France

Introduction

Shrinking populations, abandoned pastures, and depopulated settlements reflect the socio-economic transformation of the Alpine region driven by industrialization and tertiarization (Bender & Haller 2020). EU funding programs frame mountain regions as structurally disadvantaged due to low agricultural and forestry productivity (Dax 2020). This narrative is particularly evident in peripheral Alpine areas, which have long faced persistent challenges such as outmigration and infrastructure decline (Bätzing 2015). These issues remain central to public debate on a region's attractiveness and economic viability (Simmen et al. 2006).

In line with a *modern understanding of nature conservation* promoting both ecological preservation and socio-economic development (Weixlbaumer et al. 2020), protected areas (PAs) are regarded as key instruments for sustainable regional development (Job et al. 2005). Biosphere reserves (BRs) as *model regions for sustainable development* (Borsdorf & Jungmeier 2020) and regional nature parks (RNPs), preserving cultural landscapes (Weber 2013), operate within multi-level governance systems. These frameworks enable coordination across administrative levels and sectors, fostering participatory, consensus-based regional planning and development (Pütz & Job 2016; Kühne 2010).

However, the relationship between nature protection and local economic interests remains controversial since conservation is still associated with a *prohibitive character*, restricting landscape exploitation and economic activities (Borsdorf & Jungmeier 2020; Sacher & Mayer 2019; Coy & Weixlbaumer 2009). In many rural areas, particularly in the Alps, these tensions create local resentment, as communities fear losing access to critical resources for agriculture, settlements, and transportation (Simmen et al. 2006; Maschke et al. 2020). This also applies to the Mont Viso border region in the Cottian Alps, encompassing the Mont Viso (3,841 m) and parts of the Italian Piedmont and the French Provence-Alpes-Côte d'Azur. Despite its promotion to foster sustainable regional development, the designation of the cross-border UNESCO Biosphere Reserve Mont Viso (UBMV) in 2014 met with considerable resistance at the municipal level, especially in the Italian Valle Pellice, where many municipalities opposed participation due to fears of economic losses (CIPRA International 2019).

Given global conservation goals like the 30% protection target set at the UN Biodiversity Conference (COP15) in 2022, reconciling environmental protection with local economic interests is increasingly urgent. This article therefore explores how PAs stimulate sustainable economic development in remote Alpine regions. It examines the structural conditions that shape the UBMV's actions and asks whether these actions contribute to structural change in support of sustainable economic development in the Mont Viso border region. Drawing on Weber (2013), the study triangulates actor-centred institutionalism (Mayntz & Scharpf 1995) and structuration theory (Giddens 1984), conceptualizing PAs as strategic *corporate actors* in regional development. In this regard, the study defines *territorial agency* as the capacity of PAs to initiate and sustain structural transformation dependent on legal authority and financial resources.

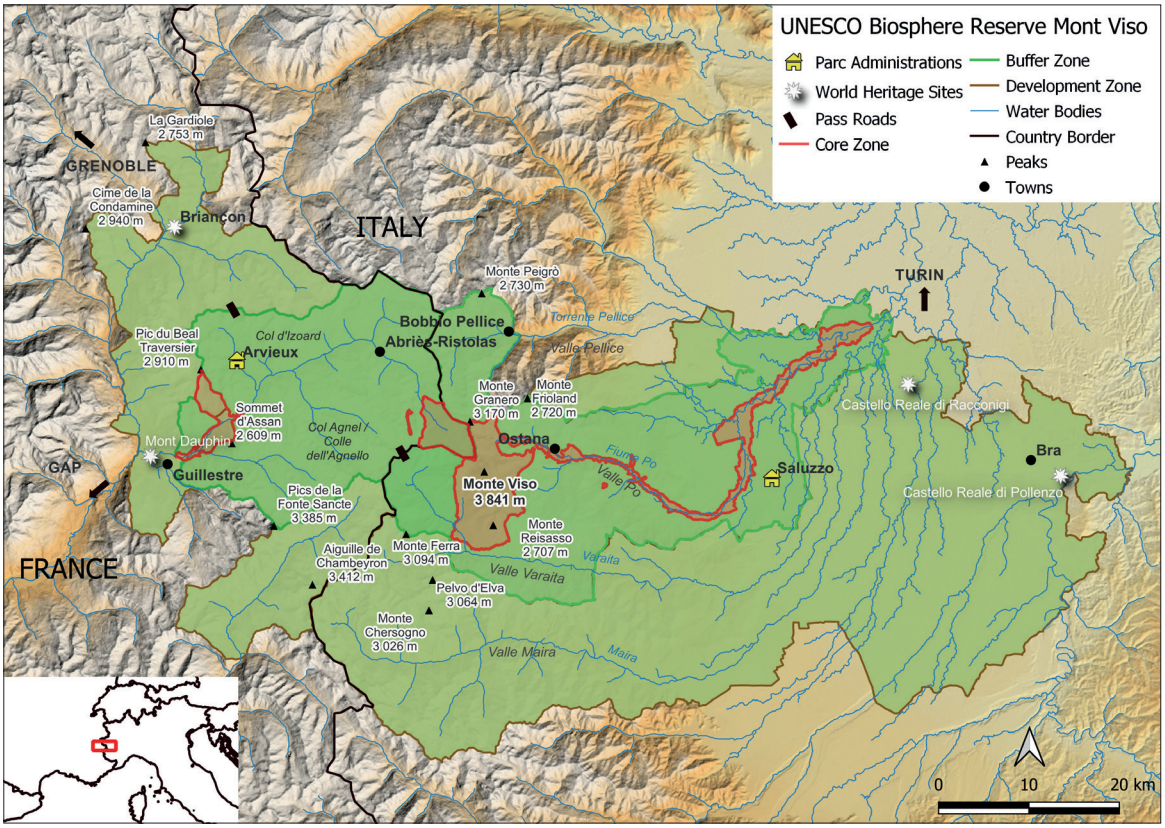


Figure 1 – The UNESCO biosphere reserve Mont Viso. Source: Copernicus 2022; Eurostat/GISCO 2016 2022; Parc naturel régional du Queyras 2022; Parco del Monviso 2022; own figure.

The Mont Viso border region

The Mont Viso border region (N44.66789089132902, E7.090466572196286) encompasses over 420,000 hectares with more than 300,000 inhabitants in the province of Cuneo in north-western Italy, and the departments of Hautes-Alpes and Alpes-de-Haute-Provence in south-eastern France. Located in an inner Alpine arid zone, the territory features the Mont Viso massif, high Alpine valleys, the Po river's source and plain, the Durance river basin and dense forests with unique wildlife and endemic species (CIPRA International 2019; Knauer & Voll 2005; Parc naturels régionaux du Monviso & Parchi naturali regionali del Monviso 2007). The region's topography limits agriculture to small-scale practices, with tourism developing more gradually than in other Alpine areas. Local crafts provide supplementary income (Parco del Monviso 2021). Barely accessible high Alpine valleys and resistance to *modern development* have contributed to a substantial exodus in recent decades, marginalizing the region (Knauer & Voll 2005).

However, nature conservation efforts since the 1980s have been successful, particularly early cross-border initiatives such as monitoring the endemic Lanza Salamander (Knauer & Voll 2005; Parc naturels régionaux du Monviso & Parchi naturali regionali del Monviso 2007). Since the beginning, the French Parc Naturel Régional du Queyras (PNRQ) and the Italian Parco del Monviso (PNRMV) cooperated closely, culminating in the transnational designation of the UBMV in May 2014. Jointly managed by the two RNPs, the UBMV aims to establish cross-border governance for a common territorial development strategy, promoting a socio-ecological transition and fostering exchanges between high alpine valleys and river plains while emphasizing the region's cultural heritage. But the idea met with resistance in the Pellice Valley. On the Italian side, the park official overseeing the UBMV characterizes the negotiations as follows:

"*When the authorities* [of the Piedmont region] *wanted to expand the park area, there were many reactions. Meetings were organized, the authorities were represented there, and it was a strong argument, not physically, but very, very strongly polemical. And the authorities understood there was no possibility of extending the park there.*" (Author's translation)

This is why the UBMV territory is cut to the north (Figure 1).

Conceptual background

The EU's regional development strategy adopts an integrative policy paradigm that seeks to promote the endogenous potential and ecological resources of rural regions through *territorial governance*, defined as coordinated action among public and private stakeholders at the regional level (Böcher 2009; Esparcia & Abbasi 2020). This has evolved into a *neo-endogenous* ap-

proach, emphasizing intersectoral coordination within multi-level governance arrangements (Dax 2020). In this context, PAs such as BRs and RNPs are seen as instruments for sustainable regional development, particularly in economically weak, peripheral regions (Job et al. 2005). Established through participatory processes, they facilitate vertical and horizontal coordination across political frameworks and policy sectors (Pütz & Job 2016). While nature preservation aims to maintain a territory's *ecological function* (Hammer 2003), the modern paradigm of nature conservation integrates ecological protection and socio-economic development (Weixlbaumer et al. 2020). This is particularly evident in BRs, envisioned as *model regions for sustainable development* (Borsdorf & Jungmeier 2020), and RNPs, preserving cultural landscapes (Weber 2013). They contribute to the protection of fragile ecosystems and the socio-economic development of a region (Broggi et al. 2017; Weber 2013). Yet their economic impact remains contested, prompting calls for further research beyond tourism (Price et al. 2021; Sacher & Mayer 2019; Mayer & Job 2014).

Drawing on Weber (2013), this study triangulates Giddens's theory of structuration (1984) and the concept of actor-centred institutionalism according to Mayntz & Scharpf (1995) to assess the impact of the UBMV and its two managing organizations, the PNRQ and the PNRMV, on sustainable economic development in a peripheral mountain region. The study analyses PAs' strategic behaviour as corporate actors within regional development processes. It focuses on the actions of the UBMV, seeking to reconstruct the material and legal resources it draws upon in its actions. This theoretical-conceptual approach enables the analysis of interactional changes. It offers insights into the extent to which the UBMV controls processes and dynamics that either support or constrain sustainable economic development at the regional level. Particular attention is given to its capacity to promote sustainable economic development through structural transformation.

Methods

The study used a qualitative approach to explore the functioning of the two RNPs and the UBMV, focusing on identifying factors that motivate or hinder action. Semi-structured interviews were conducted with PA administration representatives, regarded as administrative and internal organizational processes experts. To assess the impact of activities and measures on those directly affected and the influence of PAs on local economic development, additional interviews were conducted with local economic stakeholders, including tourism professionals, artisans and farmers. In total, 17 interviews were completed during a 4-week field trip in spring 2022, with participant contact facilitated through the *gatekeeper* function (Mattissek et al. 2013) of UBMV employees in France and Italy. The research strategy followed a deductive logic in line with Mayring's (2015) approach to qualitative content analysis. Based on this multi-perspective theoretical framework, a theory-guided coding scheme was developed to categorize the interview material according to the study's analytical interest. The analysis aimed to identify the spatial and social structures that shape and constrain the three PAs in the Mont Viso border region, helping to evaluate the extent to which they exercise agency in mobilizing or reshaping these structures to foster sustainable economic development.

Results

The analysis reveals that the differing national and historical structural conditions of each PA lead to inconsistent interpretations of sustainable development in the Mont Viso region, influencing the UBMV's efforts to promote sustainable economic development.

Legal and material means for actions

The 2014 UNESCO designation was followed by an interministerial agreement between France and Italy, formalizing transnational collaboration and establishing a legal framework for the UBMV. This joint *MAB Mon Viso* (MAB – UNESCO Man and the Biosphere program) dossier promotes sustainable development

Infobox

French Parc Naturel Régional du Queyras (PNRQ)
The PNRQ, established in 1977, is one of France's oldest and smallest nature parks. Created under the 1967 national decree on regional nature parks, it promotes sustainable regional development while preserving the landscape. It operates under a 5-year charter and is funded by local municipalities, the Provence-Alpes-Côte d'Azur region, and public and private sponsors.

Italian Parco del Monviso (PNRMV)
Reorganized in 2016 under Regional Law No. 19 (2015), the PNRMV focuses on nature conservation across Monte Viso's slopes and the River Po, encompassing several smaller conservation areas. In addition to managing these protected areas, the PNRMV oversees research and environmental education and promotes sustainable agriculture and tourism. The Piedmont region and local partnerships fund it.

UNESCO Biosphere Reserve
The UNESCO biosphere reserve designation zoned the Mont Viso border region into: a *core zone*, including the PNRMV and the *Réserve naturelle de Ristolas* within the PNRQ under existing conservation laws; a *buffer zone*, covering the rest of the PNRQ and the Italian Valle Varaita, focusing on sustainable resource management; and a *development zone*, including the lowlands, Valle Maira, and Vallée de l'Ubaye, promoting sustainable development without legal restrictions (see also Figure 1).

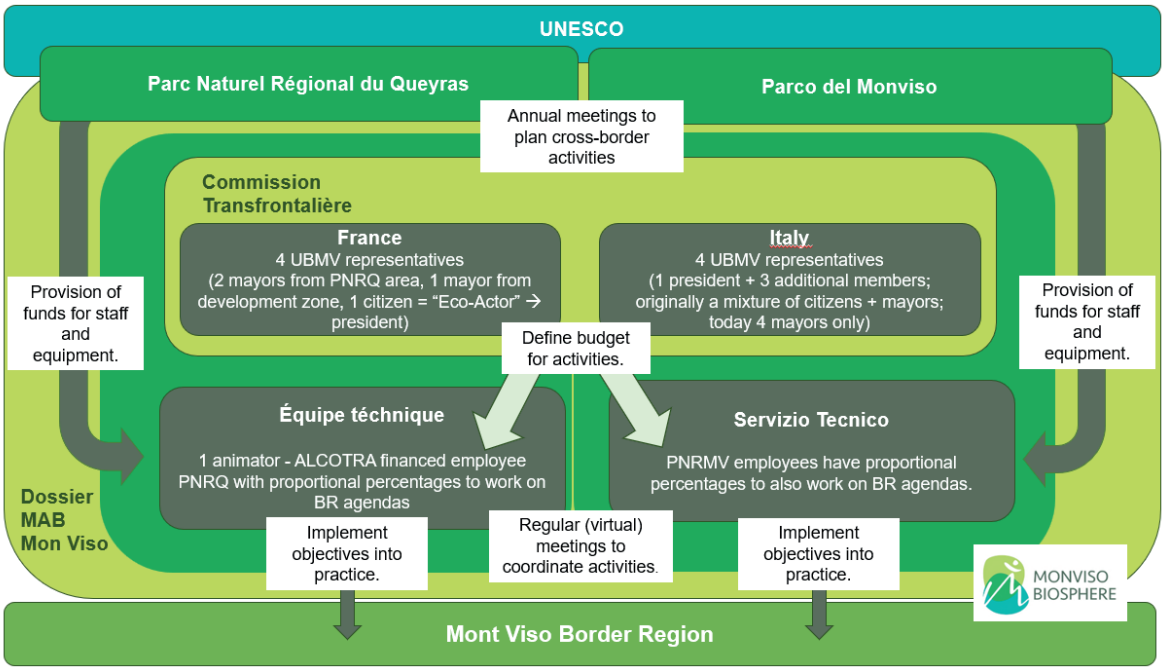


Figure 2 – Legal and Material Means for actions. ALCOTRA – INTERREG ALCOTRA program (Alpes Latines COopération TRAnsfrontalière); MAB – UNESCO Man and the Biosphere program; PNRMV – Italian Parco del Monviso; PNRQ – French Parc Naturel Régional du Queyras; UBMV – UNESCO Biosphere Reserve Mont Viso. Source: own design.

aligned with the core, buffer and development zones. The joint UBMV management is complemented by a transnational commission (*Commission transfrontalière* or *Commissione transfrontaliera*) to plan BR activities. Since UNESCO does not allocate material resources, the two RNPs fund staff and equipment costs. Additional funding is secured through public tenders, particularly from the INTERREG ALCOTRA program (*Alpes Latines COopération TRAnsfrontalière*) supporting cross-border collaboration. Several UBMV actions are also co-financed by the respective environmental ministries, enabling the PNRQ to hire a dedicated employee to oversee UBMV actions (Figure 2).

Actions

The UBMV pursues three objectives: conserving biodiversity; promoting sustainable development that favours cultural heritage and a *green economy*; and providing technical assistance for local sustainable economic practices. One initiative that specifically aims to promote sustainable economic development is the *Eco-Actor* network (*Éco-Acteurs* or *Eco-Attori*), targeting individuals, businesses, associations and cooperatives. Participants must already be engaged in sustainable development and seek to expand their commitment. Candidates submit a dossier outlining goals they aim to pursue in alignment with the Sustainable Development Goals (SDGs). Upon review by park staff, successful applicants sign a *Declaration of Commitment* (*Charte d'Engagement'* or *Carta d'Impegno*) and receive a plaque (Figure 3).

The award recognizes commitment to sustainable development, positioning *Eco-Actors* as sustainability ambassadors. Through voluntary meetings and trainings, the UBMV established a network of like-minded individuals, promoting exchange and collaboration within the BR. *Eco-Actors* represent various economic activities, including organic farming; craft cooperatives; hospitality businesses; restaurants focused on circular economy principles and regional products; and travel and event agencies connecting tourists with the local culture and population.

The two RNP administrations coordinate local involvement, though resource disparities between the PNRQ and the PNRMV affect the coordination. Communication on BR-related topics, for instance, depends on each RNP's capacity to integrate them into their websites, newsletters and social media. National differences also exist in external stakeholder involvement. While *MAB France* sets BR guidelines and offers advisory support, Italy coordinates actions with the Ministry of the Environment in the absence of a similar body.

Scope for action

The UBMV builds on natural and socio-cultural similarities, with transnational collaboration viewed by the local population as key to addressing current challenges and strengthening prospects. In this context, the joint *MAB dossier* legally supports involving a significantly greater number of municipalities and a larger population in sustainable development activities, expanding the spatial and thus operational scope of the two RNPs. Additionally, interviewees emphasized that the legal framework provides more autonomy in priority-setting than the PNRQ and the PNRMV legal



Figure 3 – Logo of the Eco-Actors *of the UBMV and plaque of the Italian* Valle dell'Eco *cooperative. Sources: Parco del Monviso 2021. © Sauerwein-Schlosser*

bases. For the PNRMV, this represents an opportunity to overcome legal constraints since UBMV management allows the Italian park administration to address a broader range of issues and collaborate with stakeholders beyond its core nature conservation role.

Moreover, the UBMV's actions and interactions benefit the population economically. While the BR designation did not impose additional restrictions, UBMV initiatives support sustainable economic activities. As such, the *Eco-Actor* network enhances the visibility and scope of niche economic activities. Sustainable development in the UBMV is furthermore based on the principle of voluntarism, respecting individual motivation while promoting alignment with the SDGs and identification with the Mont Viso region. In this context, the UBMV's assistance for *Eco-Actors* helps to access financial resources and political representation that agricultural cooperatives, artisan groups and small hospitality businesses lack compared to politically influential traditional sectors.

Transnational collaboration further amplifies these efforts, aligning with the region's socio-economic realities. Several cooperatives and local businesses, including French *artisan collectors* and an Italian craft cooperative specialized in mountain architecture, already engage in cross-border activities. The UBMV's actions enhance these local economies, create new economic links and expand markets, such as a French artisan cooperative now stocking Italian products. Overall, the UBMV strengthens and extends sustainable economic cycles in the region.

Limits of action

However, the main obstacle is a lack of legal and material resources. Unlike RNPs governed by national or regional laws, BRs lack binding authority, making their implementation voluntary. Moreover, the sponsorship division between the two RNPs creates dependency and power imbalances, positioning the UBMV as a subordinate administrative task. One of the interviewees from the PNRQ administration illustrates this with an example:

"*A colleague working on agriculture has done a lot of work on food in an area that is larger than that of the park, and even a little larger than that of the French part of the Réserve du Mont Viso. But he has never advertised these actions as being within the framework of the Réserve du Mont Viso. And yet, it was perfectly in keeping with the idea of a biosphere reserve. However, as the Réserve du Mont Viso did not finance it, he worked with other partners who were not in the same area. That is the difficulty with all these geographical differences and different structures. A lot is going on in the Réserve du Mont Viso. But we do not necessarily say that the Rèserve is doing it.*" (Author's translation)

This situation also affects transnational collaboration. The PNRQ and the PNRMV hold decision-making power, while the *Transnational Commission* has been inactive since 2017, weakening its legitimacy. Consequently, transnational collaboration is undermined, as the RNPs' decisions are based on local conditions and interests without comprehensive transnational coordination. Furthermore, the PNRQ's dedicated employee benefits only the French side, leaving the PNRMV to manage tasks independently, creating a sense of inequality.

Additionally, the interests of municipalities in the development zone are insufficiently considered, and the UBMV's reliance on the RNPs' communication channels further complicates engagement. The UBMV's spatial lack of visibility contributes to a blurred distinction between different PAs in the public's perception, with the BR category only partially recognized. Unless directly involved, locals lack understanding of the UBMV's objectives, highlighting the need for greater outreach. *Eco-Actors*, moreover, feel their network is not fully leveraged, citing infrequent meetings and a lack of promotional materials, such as flyers or brochures. However, limited material means hinder such efforts. Furthermore, the *Eco-Actor* award is criticized as a certification with limited consumer signifi-



Figure 4 – Comparison of the economic benefits of different awards. © Sauerwein-Schlosser

cance. Unlike the *organic* label or *Booking.com* awards, it lacks specific quality attributes and recognition (Figure 4). At the time of data collection, the Covid-19 pandemic had severely impacted UBMV actions, especially cross-border exchanges between *Eco-Actors*. However, the physical inaccessibility of the Mont Viso massif remains a structural barrier even beyond the pandemic, distinguishing the UBMV from other cross-border EU projects.

The UBMV thus demonstrates strength by transcending the spatial and conceptual boundaries of the PNRQ and the PNRMV, expanding cross-border interactions. This ability is key for initiating structural transformation. The UBMV can be understood as adopting a *territorial governance approach*. However, its engagement in sustainable development through socio-cultural and socio-technical innovations remains selective. Limited by the absence of legally defined responsibilities and insufficient financial and human resources, the UBMV falls short of its stated goal to "*reconcile nature conservation and biodiversity preservation with human activities*", as the French UBMV employee noted. These limited means of action hinder the UBMV from exercising the full *territorial agency* necessary to support a sustainability transition in the Mont Viso region.

Discussion

PAs are seen as key instruments for sustainable regional development in the Alps, though concerns about economic restrictions due to conservation measures remain. The Mont Viso case exemplifies this tension, where low awareness of PA objectives hinders understanding and acceptance (Lindern et al. 2020). Yet, the analysis reveals a more nuanced reality. Instead of imposing additional conservation constraints, the UBMV designation expanded the existing RNP territories through a *development zone*, enabling support for entrepreneurial and socio-cultural niche activities and strengthening cross-border socio-economic dynamics. While this approach reflects a basic form of *territorial governance* in line with the SDGs, structural frameworks alone are insufficient to drive transformative change.

Effective contribution to regional development requires PAs to go beyond coordination and consensus-building and to develop a *territorial agency*. This agency depends on legal and financial resources. PAs equipped with strong institutional mandates, adequate funding and sufficient personnel may promote sustainable economic development in peripheral mountain regions by supporting bottom-up initiatives, stimulating socio-economic dynamics and preserving unique natural and cultural assets, thereby advancing sustainability transitions.

Yet PA designations are often politically motivated to stimulate rural economic development (Pütz & Job 2016). Such instrumentalization can conflict with broader sustainability goals that emphasize long-term *responsible* resource use over short-term growth. In this study, *adding value* is thus redefined as enhancing regional potential and economic cycles. However, communicating this shift in purpose remains difficult, particularly with regard to how effectiveness is measured. Although monitoring is central to PA management, it often lacks practical relevance for decision-makers and stakeholders (Huber & Köstl 2020). To address this, value chain analysis offers useful insights into the economic impact of PA management on regional income (Kraus et al. 2014). It can be complemented by solid sustainable tourism planning (Job et al. 2017) and by advancing strategic levers, such as expanding market-based tools like the *Eco-Actor* label, integrating economic themes into education for sustainable development (Kraus et al. 2014) and diversifying local economies (Hora 2017).

Ultimately, the ability of PAs to act as *transition managers* (Frantzeskaki & Loorbach 2012) depends not only on institutional frameworks, but also on the quality of governance practice. In the Mont Viso region, political representatives control decision-making, resulting in a *top-down governance* model (Pflitsch & Strambach 2018). This can cause *ecological errors*, where political and economic priorities override spatial characteristics and endogenous development potentials (Marsden 2012). To counteract such dynamics, PAs must align with the principles of *good governance* (Broggi et al. 2017). In addition to improving socio-economic monitoring and planning (see also Buer et al. 2014), implementing a *comprehensive and transparent communication strategy* is essential in actively involving local communities (Baumgartner et al. 2022). Only through such reflexive and inclusive approaches can PAs successfully balance conservation with socio-economic development, thereby becoming effective agents of sustainability transitions in Alpine regions.

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Author

Carlotta Sauerwein-Schlosser

PhD candidate within the Working Group Development and Sustainability Research at the Institute of Geography, University of Innsbruck. Her research focuses on regional developments in mountain regions and socio-ecological transformations in natural resource governance.

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Do we collect adequate and relevant biodiversity data? A case study of the Malá Fatra National Park (Slovakia)

Dana Repáňová & Juraj Švajda

Keywords: biodiversity, monitoring, protected area, hotspot, conservation management

Abstract

Monitoring biodiversity is crucial for comprehending the status and distribution of species, thereby aiding in the management and conservation of protected areas. Malá Fatra National Park, renowned in Slovakia for its natural richness and environmental diversity, has undergone biodiversity monitoring for decades, with data consolidated in the Comprehensive Information and Monitoring System. This study assesses mapping efforts across various taxonomic groups within the park and highlights characteristics of adequately mapped groups. It presents heat maps depicting biodiversity hotspots generated through QGIS, analysing 48,995 observations and 1,558 mapped plant and animal species by the end of 2022. Findings indicate that plants represent the most mapped organism group, while animals record the highest number of observations. Mapping levels vary significantly across taxonomic groups, with Tracheophyta, Aves and Mammalia relatively well-mapped, contrasting with poorly mapped groups such as Bryophyta and Invertebrata. Geographically, Rozsutec and Suchý Nature Reserves are the best-mapped areas, with Rozsutec identified as a significant hotspot. These results underscore the necessity for intensified mapping efforts to enhance understanding of the area's biodiversity and species distribution.

Profile

Protected area

Malá Fatra National Park

Mountain range

Western Carpthians

Country

Slovakia

Introduction

Long-term biodiversity monitoring is vital for understanding the dynamic and complex nature of ecosystems, providing critical data to inform management interventions aimed at conservation and sustainability. Protected area management heavily relies on such monitoring to offer insights into population trends, identify early warnings for conservation challenges and evaluate conservation effectiveness (Lindenmayer et al. 2011). Reliable and scientifically robust data are essential for detecting trends such as population declines or shifts in species distributions. These insights enable informed decisions about where and how to implement conservation actions (Downey et al. 2021) and support the evaluation of management measures. Adaptive management practices can be adjusted as new information becomes available, ensuring that conservation strategies remain effective over time (Dalton et al. 2024).

National and local governments must strengthen their commitment to implementing the Convention on Biological Diversity to halt and reverse ongoing biodiversity loss (Perino et al. 2022). Biodiversity monitoring plays a critical role in achieving the goals of the 2030 Global Biodiversity Framework, the European Biodiversity Strategy and the EU Green Deal. However, current efforts face challenges, including gaps and biases in taxonomy, spatial coverage and temporal resolution, leading to fragmented and disconnected data (Moersberger et al. 2024).

Databases are increasingly employed worldwide to consolidate, analyse and share biodiversity data, enabling better decision-making for conservation and sustainable management. Despite their advantages, such as facilitating the tracking of long-term ecological changes and fostering collaboration, these databases often face challenges related to data completeness, quality variability and limited interoperability (Feng et al. 2022; Spear et al. 2023).

Global biodiversity estimates suggest that Earth harbours approximately 8.75 million species, yet less than 15% have been catalogued (Mora et al. 2011). By 2022, the IUCN Red List had assessed 150,388 species, of which over 42,100 were categorized as threatened, including more than 9,000 species classified as Critically Endangered (CR). In Slovakia, over 11,270 plant species and 28,800 animal species have been documented, making it one of Europe's most biodiverse countries relative to its size (Ministry of the Environment of the Slovak Republic 2013; Sabo et al. 2011). Of the 5,000+ assessed species, nearly 350 are considered threatened (IUCN 2023), with habitat conversion and degradation being the primary drivers of biodiversity loss.

Biodiversity supports ecosystem functionality and resilience, underpinning ecosystem services and contributing significantly to global economies (Mace et al. 2012; Sukhdev et al. 2010; World Economic Forum 2020). While biodiversity hotspots are crucial for conservation prioritization, they do not universally align with ecosystem significance, highlighting the need for



Figure 1 – Geographical location of Malá Fatra National Park within Slovakia, providing context for the study area.

comprehensive biodiversity assessments beyond hotspot paradigms (Marvier & Kareiva 2003; Norman & White 2019). Such assessments are foundational for guiding conservation priorities, diagnosing ecological issues, and planning interventions (Sutherland 2000).

Malá Fatra National Park (NP), located in Slovakia's Alpine biogeographical region, was established in 1967 and spans 226.3 km². It encompasses 18 smaller protected areas, including 14 national nature reserves, three nature reserves and one nature monument. Nearly 98% of the park overlaps with the Special Area of Conservation SKUEV0252 and is entirely part of the Special Protection Area SKCHVU013, both under the Natura 2000 network. As the westernmost Carpathian park, Malá Fatra supports original ecosystems and serves as a critical corridor for large carnivore dispersal to Western Europe (Malá Fatra National Park Administration 2023).

The park's geological substrate is diverse, ranging from granites and granodiorites in the south to limestone, dolomite, quartzite and slate in other areas. Forests cover two thirds of its territory, with vegetation types varying from beech-oak forests to dwarf pine communities. The park also preserves subalpine, rocky and scree habitats alongside meadow, pasture and wetland biotopes. Twenty-six habitat types, six plant species and 29 animal species of European importance have been identified within the park (Malá Fatra National Park Administration 2023). However, anthropogenic pressures such as increased recreational activities, forest management, harvesting, hunting and the decline of traditional meadow and pasture practices significantly threaten these ecosystems.

This study evaluates biodiversity mapping efforts in Malá Fatra NP using data from the Comprehensive Information and Monitoring System (CIMS). The analysis focuses on taxonomic groups of plants and animals, identifying gaps in current mapping efforts, highlighting biodiversity hotspots and prioritizing areas for future monitoring. The study addresses the following key questions: What is the current mapping status of various taxonomic groups in the CIMS? Which taxonomic groups are underrepresented? How do current mapping efforts reflect biodiversity hotspots within the park? On what areas should future mapping efforts focus to address data gaps and improve conservation strategies?

Materials and methods

The CIMS, established in 2015, is a database platform designed to consolidate field monitoring data and other occurrence records of habitats and species for processing, analysis and evaluation (Saxová & Černecký 2014). The CIMS infrastructure includes hardware components (blade servers, management server, disk array and hardware firewall) and an application layer consisting of MS Windows Server, ArcGIS for Server and MS SQL Server. The platform is divided into two user-accessible sections: an internal system for protected area staff in Slovakia and a public portal for disseminating monitoring results and gathering occurrence data. Spatial data is stored within a unified relational database and a mobile application (compatible with Android OS) is available for data entry, accessible via the public portal.

Data collection in the CIMS primarily focuses on species of European significance, essential for Natura 2000 site reporting. Additional data on species tied to specific natural characteristics or park activities (e.g. forest and grassland species) are gathered as part of the national park's monitoring responsibilities. Field data is entered into the system by specialized personnel, such as rangers, zoologists and botanists, using either the mobile or desktop application. Public-submitted observations are validated by park staff and sensitive data, such as locations of critically endangered species, remain accessible only to internal users. For this study, only occurrence data from the CIMS were used.

Data sources

For our analysis, we used botanical and zoological data from the CIMS for Malá Fatra NP up to the end of 2022. The dataset includes recent entries and historical records from the former Information System of Taxons and Biotopes (ISTB) database established in 2001, as well as data from various publications dating back to the 1950s. Data were extracted from the CIMS in Excel format, comprising approximately 30 attributes (e.g. abundance, coverage for plants and development stages for animal species). For this study, we focused solely on scientific species names and corresponding coordinates.

Data processing

The extracted records were imported into QGIS to create a vector layer confined to the Malá Fatra NP territory using the *Intersect* tool. The dataset was subsequently divided into two separate Excel files for botanical and zoological records. Each record was categorized into basic taxonomic groups (kingdom, phylum, class and order), with species assigned to the

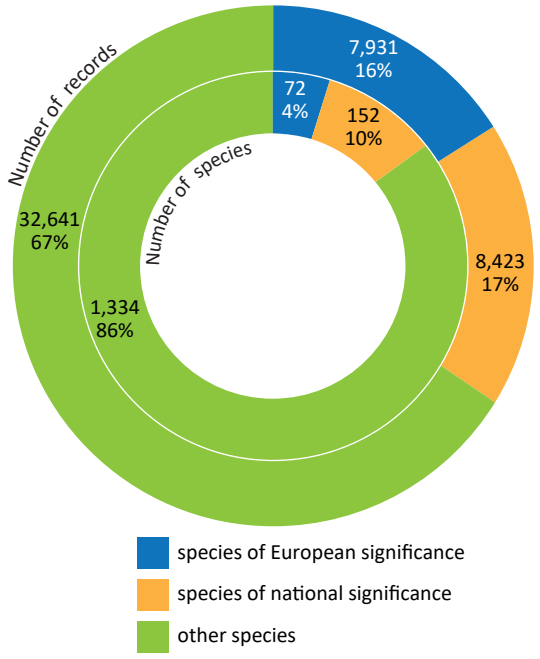


Figure 2 – Comparison of the total number of mapped plant and animal species and associated records in the CIMS for Malá Fatra National Park. The inner circle represents the distribution of species, while the outer circle illustrates the corresponding number of records.

appropriate Global Biodiversity Information Facility (GBIF) taxonomic group. This disaggregation facilitated analysis of the number of mapped species and records per taxonomic order, focusing on species of European (Birds or Habitats Directive) and national significance (endangered, vulnerable, rare or endemic).

Analysis of protected areas

To analyse species distribution within smaller protected areas (PAs) overlapping Malá Fatra NP, we used QGIS to clip the PA vector layer with the national park boundary using the *Intersect* function. This process yielded a new vector layer containing only PAs within the park. Separate vector layers for botanical and zoological data were generated for each PA by iteratively applying the *Intersect* tool. Using these layers and their attribute tables, the number of mapped species and records in each PA were analysed.

Visualization and heat maps

Three additional columns were added to the attribute table of PAs overlapping Malá Fatra NP, representing the total number of species, plant species and animal species. Graded symbology was applied in QGIS to generate map outputs showing the total number of mapped species, as well as plant and animal species distributions.

For botanical data, unique coordinates were unavailable due to plot-based mapping practices, where plant species are recorded across permanent monitoring plots using a single GPS coordinate. Therefore, a biodiversity hotspot map was generated exclusively for zoological data. Using the *Interpolation – Heat maps (Kernel Density Estimation)* tool in QGIS with a 1,000-metre radius, hotspot maps were created to identify clusters of high-density zoological records, representing areas with concentrated biodiversity data.

Methodology limitations

It is important to note that the methodology inherently reflects biases in data collection and avail-

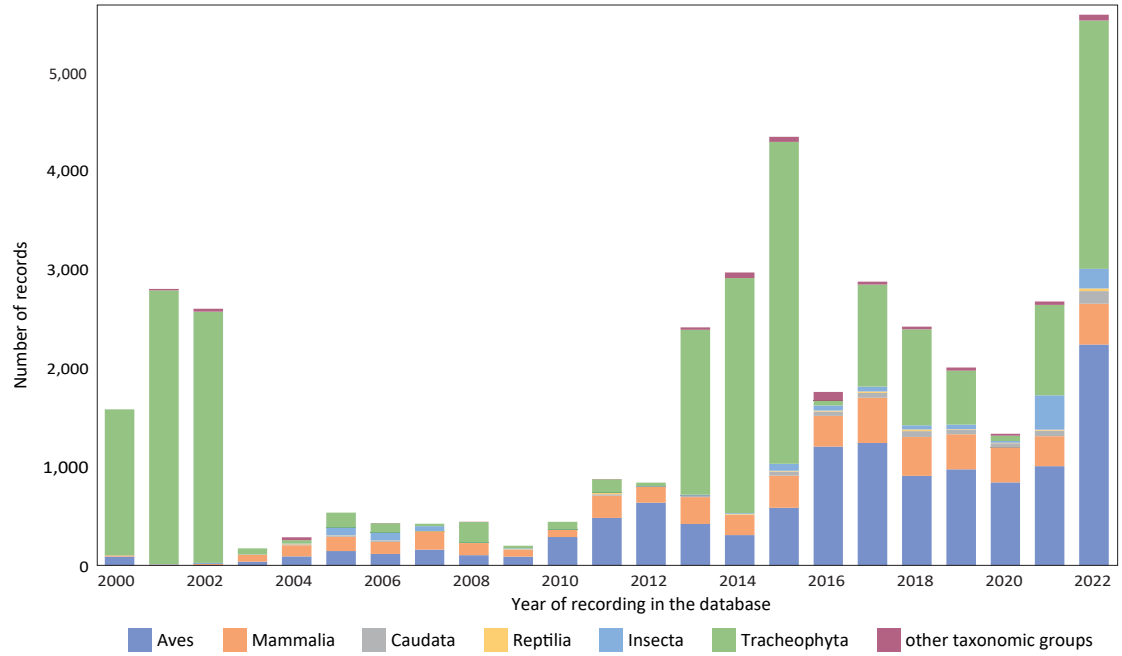


Figure 3 – Annual trends in recorded biodiversity data in the CIMS for Malá Fatra National Park, segmented by taxonomic groups (2000–2022; subsample size: n = 39,975 records). A subsample dataset was selected for better visualization and practical purposes, reflecting the volume of data collected over the last period, including methodological consistency and precision.

ability, particularly for botanical data due to plot-based mapping and the historical nature of some zoological records. These limitations underscore the need for targeted efforts to fill data gaps and improve the comprehensiveness of biodiversity monitoring within Malá Fatra NP.

Results

By the end of 2022, data within the CIMS database revealed a predominance of mapped species within the plant kingdom. However, animal records accounted for the highest number of occurrences. In total, nearly 50,000 records were catalogued, encompassing over 1,500 species across various taxonomic groups (Table 1).

Table 1 – Summary of species diversity and record counts in the CIMS database for Malá Fatra National Park, categorized by taxonomic unit and groups (for more details, see appendix).

Organism group	# Species	# Records in the CIMS
Animals		
Arthropoda	203	2,654
Mollusca	98	4,241
Annelida	1	1
Chordata	243	18,019
Total (Animals)	545	24,915
Plants		
Tracheophyta	928	23,837
Bryophyta	62	214
Marchantiophyta	23	29
Total (Plants)	1,013	24,080
Total (Animals & Plants)	1,558	48,995

Species of European and national significance

While species of European and national significance represented a smaller portion of the total dataset, they contributed to approximately one third of the total records (Figure 2).

Temporal patterns in data recording

The annual progression of biodiversity records in the CIMS from 2000 to 2022 showed fluctuating trends without a clear increase or decrease (Figure 3). Notably, 2003 and 2009 recorded the least data entries (175 and 202, respectively), while 2015 and 2022 recorded the highest volumes, with 4,334 and 5,570 entries, respectively. The disparity between the highest and lowest annual entries represents a 96% difference, indicating variability in mapping and monitoring efforts.

Detailed plant kingdom mapping

Tracheophyta emerged as the most extensively mapped phylum, accounting for nearly 99% of plant records (Table 1). Within this phylum, 928 species were documented across 35 orders. In contrast, Bryophyta was significantly underrepresented, with 62 species and 214 records, and Marchantiophyta was the least represented, with only 23 species and 29 records.

Detailed animal kingdom mapping

Within Malá Fatra NP, the animal kingdom was mapped across four phyla, with Chordata – primarily vertebrates – being the most extensively studied. Among vertebrates, Aves was the most thoroughly mapped class, encompassing 168 species and 12,452 records, which accounted for nearly half of all animal records. In contrast, Invertebrata groups such as Arthropoda and Mollusca were notably underrepresented, collectively contributing significantly fewer records compared to Chordata.

Geographical distribution and biodiversity hotspots

The Rozsutec National Nature Reserve (NPR) emerged as the most thoroughly mapped area in Malá Fatra NP, contributing nearly a quarter of all records from small-scale protected areas and nearly 9% of the park's total records. A total of 585 species were documented in Rozsutec NPR. NPR Chleb followed closely, with the highest number of plant species and records within the database, including the species with the most occurrences overall (Figure 4).

Zoological biodiversity hotspots were concentrated in Rozsutec NPR and its vicinity, particularly in the central and eastern areas adjoining Tiesňavy NPR. Another significant cluster of records was observed within and around NPR Šrámková. Conversely, areas such as the northern territories of Suchý NPR, Prípor NPR and Veľká Bránica NPR exhibited lower densities of zoological records (Figure 5).

Discussion

Malá Fatra National Park (NP) is recognized for its remarkable biodiversity, hosting 1,141 species of lower plants, 973 species of higher plants, 3,000 invertebrate species and 210 vertebrate species (Malá Fatra National Park Administration 2023). However, our analysis reveals that only 1,558 plant and animal species are mapped within the CIMS across the park. This number is strikingly low compared to the official data. The findings highlight a significant gap, with over two thirds of species unmapped, emphasizing the incomplete representation of biodiversity in the region. The consistent and growing trend in biodiversity records underscores the need for a stable and enduring platform for collecting and storing monitoring data, as demonstrated by the transition from the ISTB database to the CIMS.

Underrepresented taxonomic groups

Several taxonomic groups are critically underrepresented. For instance, Bryophyta have only 62 species mapped in the CIMS, compared to the nearly 700 species documented in Slovakia (Kubinská & Janovicová 2000). This discrepancy suggests a potentially higher Bryophyta species diversity in Malá Fatra NP. March-

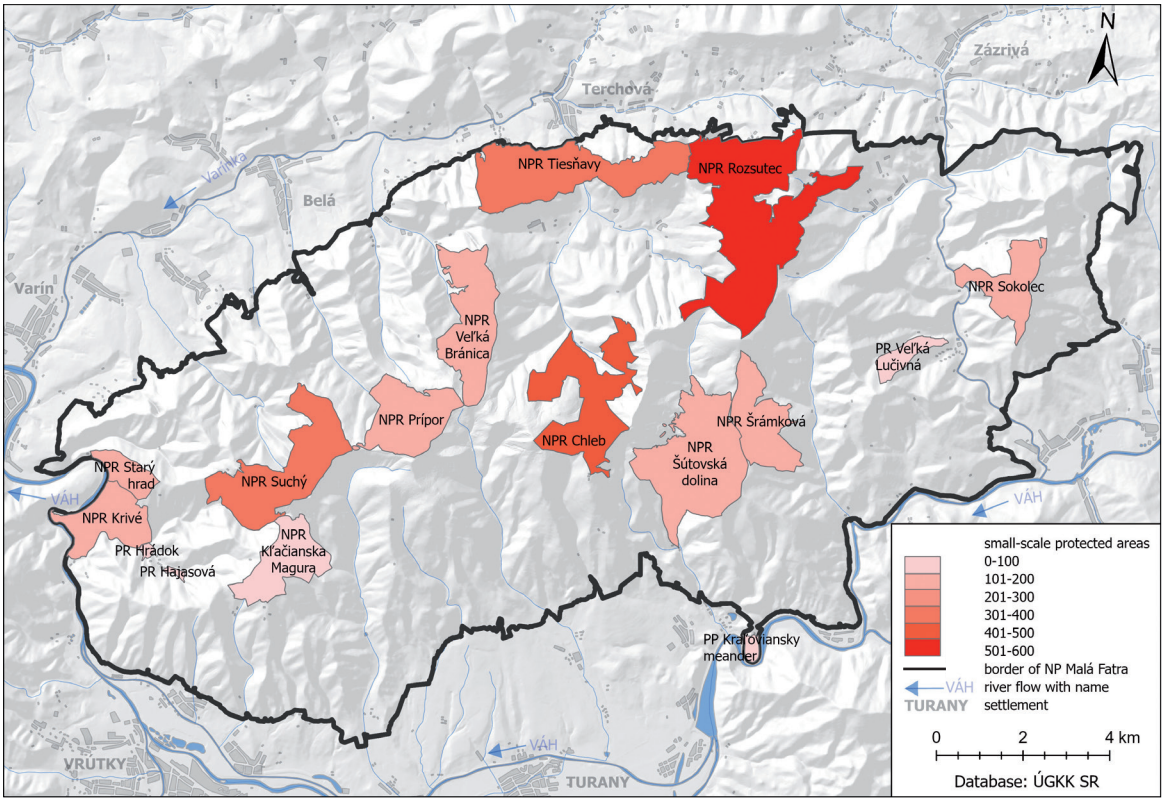


Figure 4 – Number of species mapped within small-scale protected areas of Malá Fatra National Park (NPR – national nature reserve, PR – nature reserve).

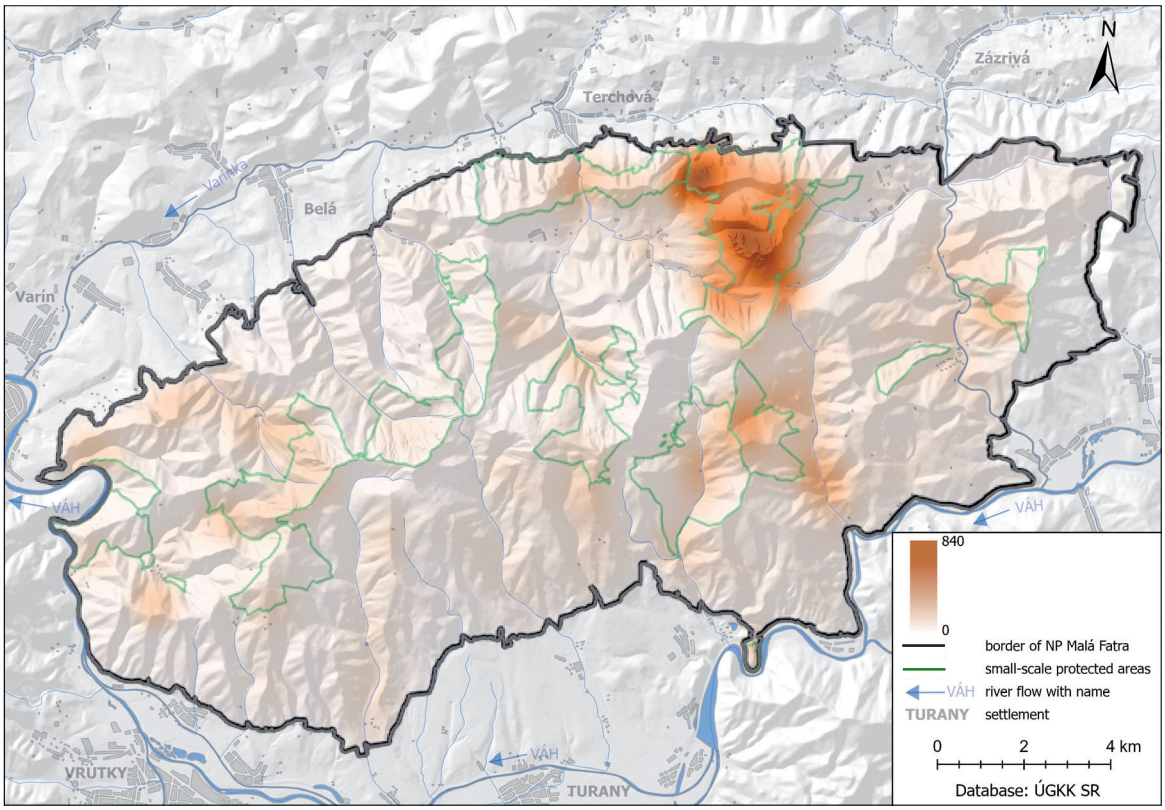


Figure 5 – Heat map depicting zoological biodiversity monitoring hotspots in Malá Fatra National Park, highlighting areas of concentrated survey efforts.

antiophyta is similarly underrepresented, necessitating enhanced mapping efforts.

Fungi, including Lichinales, are another group requiring attention. Their ecological importance as bioindicators and contributors to ecosystem functions, such as decomposition, makes their mapping imperative (Warnasuriya et al. 2023). Comprehensive mapping of Fungi would not only improve understanding of their biodiversity, but also enhance environmental assessments.

Invertebrata, which are estimated to number 3,000 species in the park, are notably underrepresented, with only 6% mapped in the CIMS. Certain subgroups, such as Arachnida and Malacostraca, are minimally represented in the database. Many Invertebrata records date back to between the 1950s and the 1970s, raising concerns about their accuracy and relevance. This highlights the need for updated and intensive mapping efforts to expand species coverage and verify historical data. Challenges in invertebrate identification – arising from their size diversity, complex life cycles and varied habitats – may contribute to their underrepresentation (Lindken et al. 2024).

Aquatic Invertebrata, in particular, are poorly mapped, whereas Vertebrata, especially Aves and Mammalia, are relatively well-documented. Aves, the best-mapped group, benefit from widespread interest among both professionals and amateurs, as they can be easily monitored using direct observation or acoustic methods. Mammalia, particularly Carnivora, are also well-documented, aided by methodologies such as camera trapping and tracking signs of their presence. The disparity in mapping across taxonomic groups reflects the popularity of certain groups and the lack of expertise and resources for others (Soriano-Redondo et al. 2024).

Broader patterns in biodiversity monitoring

The taxonomic bias observed in Malá Fatra NP mirrors global trends. Troudet et al. (2017) found that widely recognized groups such as Aves, Mammalia and Tracheophyta are extensively mapped, while Arthropoda and Mollusca remain underrepresented. Similarly, Mammola et al. (2020) reported that conservation funding disproportionately favours Vertebrata, particularly Aves and Mammalia, driven by their public appeal and ease of study. These patterns emphasize the need for balanced investment and effort across taxonomic groups.

Despite the relatively high mapping levels for some groups, the overall species representation within Malá Fatra NP remains inadequate. The park spans 226.3 km² but has fewer than 50,000 species records, many of which lack precision. In contrast, Austria's significantly larger Hohe Tauern NP (1,213 km²) boasts over 500,000 records and 12,000 species in its database (National Park Hohe Tauern 2023; Lindner et al. 2022). Hohe Tauern NP has achieved consistent annual data growth since 2004, a trend partly driven by volunteer contributions, which are largely absent in Malá Fatra NP. This difference highlights the importance of involving citizen scientists in biodiversity monitoring (Zulka et al. 2022).

Spatial patterns in mapping efforts

Mapping within Malá Fatra NP is geographically uneven, with the highest species concentrations recorded in the Rozsutec and Chleb reserves. Smaller reserves, such as Starý hrad, exhibit high species density per hectare despite their lower total species counts. It is crucial to interpret these spatial patterns cautiously, as biodiversity hotspot maps often reflect the intensity of mapping efforts rather than actual species richness. Similarly, *white spots* on maps indicate insufficient study rather than low biodiversity.

Future directions

Significant efforts are needed to map underrepresented taxa and taxonomic groups. Mapping initiatives should prioritize areas currently appearing as *white spots* on biodiversity maps, focusing on insufficiently studied locations rather than assuming low biodiversity. The integration of online digital data into biodiversity monitoring is also crucial for improving the quality and accessibility of information needed for conservation prioritization.

The rapid decline of certain species, particularly reptiles and elusive taxa, underscores the urgency of these efforts. Emerging technologies, such as camera traps and environmental DNA, offer promising tools for addressing data gaps and rediscovering species. However, community involvement remains essential for enhancing biodiversity monitoring efforts, particularly for overlooked groups like insects (Hochkirch et al. 2022).

Adopting the FAIR principles (Findability, Accessibility, Interoperability and Reusability) in data management can further enhance the utility of biodiversity data for scientific and conservation purposes. These principles foster collaboration and enable more efficient resource use, ensuring that biodiversity data remains valuable for current and future research.

Conclusion

Effective protection and management of protected areas require a thorough understanding of species occurrence, abundance and distribution. Malá Fatra NP, despite its relatively modest size, hosts a diverse mosaic of habitats that support a wide variety of plant and animal species. The findings of this study provide a valuable global contribution by shedding light on the taxonomic and geographical biases in biodiversity data collection within protected areas. This research fills an important gap in the field of biodiversity monitoring and has the potential to enhance the effectiveness of conservation efforts by informing targeted strategies for biodiversity preservation.

To address current gaps in biodiversity understanding within Malá Fatra NP, focused efforts should prioritize underexplored regions and underrepresented taxonomic groups, such as Fungi and Invertebrata. Targeted expeditions by taxonomic experts, coupled with active involvement from local volunteers, can facilitate continuous and systematic data collection. Integrating historical records and legacy data from biodiversity databases will further enhance the completeness of species distribution maps.

These combined efforts will serve as a foundation for developing more effective conservation strategies and habitat management plans. Ultimately, the improved knowledge base will ensure the long-term preservation of Malá Fatra's rich biodiversity, contributing to broader conservation goals at regional, national and global levels.

Acknowledgments

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Authors

Dana Repáňová

Malá Fatra NP Administration, Hrnčiarska 197, SK-01303 Varín

Juraj Švajda – corresponding author

Matej Bel University, Tajovského 40, SK-97401 Banská Bystrica. E-mail: juraj.svajda@gmail.com

Appendix – Assessment of the number of mapped plant and animal species and records in CIMS by individual taxonomic units in Malá Fatra National Park.

Phylum	Class	Order	Num. of map. species	Num. of rec. in CIMS
Bryophyta	Bryopsida	Tetraphidales	1	1
		Sphagnales	6	7
		Grimmiales	2	2
		Pottiales	3	11
		Dicranales	5	43
		Leucodontales	1	2
		Buxbaumiales	1	14
		Bryales	10	22
		Polytrichales	5	27
		Hypnales	28	85
Marchantiophyta	Marchantiopsida	Marchantiales	3	3
	Jungermanniopsida	Metzgeriales	3	3
		Ptilidiales	1	1
		Porellales	1	1
		Jungermanniales	15	21
Tracheophyta	Pinopsida	Pinales	9	848
	Polypodiopsida	Equisetales	8	69
		Polypodiales	26	540
		Ophioglossales	2	25
	Lycopodiopsida	Selaginellales	1	37
		Lycopodiales	4	81
	Liliopsida	Asparagales	52	1259
		Poales	110	3549
		Liliales	9	274
		Alismatales	4	69
	Magnoliopsida	Geraniales	7	214
		Cornales	2	5
		Santales	3	35
		Boraginales	15	190
		Piperales	1	55
		Celastrales	1	107
		Oxalidales	1	77
		Brassicales	27	400
		Asterales	120	3861
		Apiales	27	1190
		Myrtales	16	251
		Dipsacales	24	421
		Malvales	8	198
		Fabales	59	1048
		Sapindales	3	208
		Saxifragales	26	416
		Rosales	74	1756
		Ranunculales	40	802
		Ericales	31	1057
		Lamiales	88	1617
		Caryophyllales	51	977
		Gentianales	26	947
		Fagales	11	375
		Malpighiales	36	824
Arthropoda	Arachnida	Araneae	7	7
	Malacostraca	Isopoda	1	1
	Insecta	Lepidoptera	55	1954
		Coleoptera	100	570
		Orthoptera	23	91
		Diptera	2	2
		Odonata	3	7
		Hemiptera	1	1
		Ephemeroptera	1	1
		Hymenoptera	10	20

Phylum	Class	Order	Num. of map. species	Num. of rec. in CIMS
Mollusca	Gastropoda	Stylommatophora	86	4035
		Littorinimorpha	1	1
		Architaenioglossa	1	71
		Ellobiida	2	107
		Stenoglossa		5
	Bivalvia	Sphaeriida	3	20
Annelida	Clitellata	Crassiclitellata	1	1
Chordata	Pisces	Salmoniformes	3	24
		Cypriniformes	3	9
		Scorpaeniformes	1	5
	Amphibia	Caudata	3	371
		Anura	6	171
	Reptilia	Squamata	9	143
	Aves	Anseriformes	6	62
		Galliformes	6	829
		Podicipediformes	2	3
		Ciconiiformes	2	34
		Suliformes	1	15
		Pelecaniformes	4	46
		Accipitriformes	10	1157
		Gruiformes	4	106
		Charadriiformes	10	97
		Columbiformes	5	281
		Cuculiformes	1	80
		Strigiformes	8	594
		Caprimulgiformes	1	3
		Apodiformes	1	4
		Coraciiformes	1	42
		Bucerotiformes	1	4
		Piciformes	10	1687
		Falconiformes	3	502
		Passeriformes	92	6906
	Mammalia	Lagomorpha	1	21
		Rodentia	11	273
		Erinaceomorpha	1	4
		Soricomorpha	5	27
		Chiroptera	16	338
		Artiodactyla	4	175
		Carnivora	12	4006

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High Andean wetlands at the climate crisis crossroads and mining extractivsm: the Parque Andino Juncal case

Aldana Calderón-Archina, Leandro Manuel Alvarez, Andrés Moreira-Muñoz & Pablo Mansilla Quiñones

Keywords: wetlands, Juncal glacier, conservation, climate change

Abstract

High Andean wetlands play a strategic role in water provision, climate regulation and biodiversity conservation. Located in the Valparaíso Region of the Central Andes of Chile, Parque Andino Juncal encompasses part of a hydrological network composed of rivers, ravines, glaciers, high Andean peatlands (vegas) and springs. Established in 2004 as a privately led conservation initiative open to the public, the park was designated a RAMSAR site in 2010. Since 2017, it has gained greater visibility as a sustainable tourism project, drawing visitors primarily from the Valparaíso Region, but also from other parts of Chile and abroad. This initiative integrates tourism with passive restoration practices. Considering the alarming vulnerability of the vegas due to climate change – particularly glacial melt and prolonged drought periods – it is essential to consider both the climatic and the anthropogenic factors threatening these ecosystems to develop climate adaptation and resilience strategies. Parque Andino Juncal offers one such alternative. However, its development may be hindered by the installation of mining projects in the area. In this context, our objective is to highlight the importance of maintaining private protected areas such as the one presented here, as they serve as strategic spaces for monitoring and mitigating the effects of climate change on fragile and vital ecosystems.

Profile

Protected area

Parque Andino Juncal

Mountain Range

Andes, Chile

Introduction

High Andean wetlands are a global priority for ecological restoration due to their role in climate regulation, water provision, carbon storage and biodiversity support. In recent years, ecosystems associated with these wetlands have gained visibility because of their increasing vulnerability to climate change (Anderson et al. 2010; Zeballos et al. 2014). One of the most visible physical effects of climate change is glacial retreat and the consequent shifts in water availability (Podgórski et al. 2023). Likewise, water bodies fed by glacial melt have undergone significant transformations. The composition and ecology of high Andean wetlands, also known as vegas, depend on hydrology, topography and disturbance regimes (Méndez 2007; Méndez 2009; Ontivero et al. 2022).

Although high-altitude wetlands are priority ecosystems, in the Valparaíso Region (Chile) their protection is limited to the designation of state or APPs, among which the private reserve of Parque Andino Juncal stands out. Spanning 13,796 hectares in the eponymous valley, it was declared a RAMSAR site of international importance in 2010. This convention fosters international cooperation and provides a protective framework that promotes the conservation and rational use of wetlands (Astrálaga 2006).

The hydrological value associated with the more than twenty glaciers and wetlands present in this valley is considerable, as they provide a vital contribution to the water supply and ecosystem services for the entire Aconcagua basin (Crespo et al. 2020; Fundación Plantae 2024). Furthermore, the park forms part of the region's biocultural heritage, shaped by the interaction of geophysical, ecological and cultural processes. This landscape reflects the territorial practices and biocultural traditions of herders and drovers who, for generations, have engaged in transhumance across the cordillera. It also holds high cultural value



Figure 1 – Canchitas *vegas, Quebrada de Navarro. © Calderón Archina 2025*

for the inhabitants of the Aconcagua Valley, especially Indigenous peoples living in these territories, as well as community and environmental organizations.

The High Andes of Chile are characterized by extreme climatic conditions and unstable substrates, making the distribution and composition of plant communities sensitive to rising temperatures and declining precipitation (Cavieres et al. 2021). Recent studies have examined the dynamics between climatic variables, local water availability and the effective extent of these ecosystems (Marcosig & Liaudat 2021). As a result, the widespread and significant retreat of glaciers and ice bodies caused by climate change (Ferri et al. 2020) presents new hydrological scenarios and challenges for natural resource management and conservation. Within Parque Andino Juncal, one key landscape unit is the *Juncal Norte* Glacier, which in recent years has shown a marked reduction in surface area due to rising temperatures (Dirección General de Aguas (DGA) 2022).

In addition to the biophysical effects of climate change, open-pit mining projects in mountain areas exert further pressure on these ecosystems, as well as on both human and more-than-human communities and the ways of life tied to these environments (Uribe-Sierra et al. 2023). Given the interplay between biodiversity and the cultural diversity of human groups that have long inhabited the Andes, this region has developed a biocultural heritage encompassing a variety of belief systems and worldviews, along with complex ancestral knowledge and practices, such as techniques for managing animals and landscapes (Leguía et al. 2021). Because of its environmental, cultural and affective significance, since 2024 multiple organizations and residents have mobilized to defend Juncal Norte Glacier against the proposed operations of the US-based mining company Nutrex, which has been conducting exploratory drilling near the park since 2017. This illustrates that, despite its RAMSAR designation, areas such as Parque Andino Juncal remain vulnerable in the absence of specific glacier protection legislation and in the face of the legal primacy of subsurface mining rights over conservation rights.

Parque Andino Juncal

In Chile, most protected natural areas are publicly owned and managed by the National Forestry Corporation (CONAF). A smaller proportion consists of private protected areas (APP), such as Parque Andino Juncal in the Valparaíso Region (https://parqueandinojuncal.cl/). Officially designated a RAMSAR site in 2010, the park has operated since 2015 as a private conservation area open to the public. It is privately owned by members of the Kenrick family, who decided to carry out a conservation project in the area. They manage the reserve themselves with the help of a small number of rangers and volunteers, and their source of funding is the entrance fee they charge for access to the park. According to the definition of the International Union for Conservation of Nature (IUCN), a protected area is a clearly defined geographical space, recognized, dedicated and managed, by legal or other effective means, to achieve the long-term conservation of nature and its ecosystem services and associated cultural values. Recently, In Chile, a law regulates state and APPs (Ley 21600). However, this initiative does not have that specific recognition yet. In 2024, it was included in the Top 100 Green Destinations, a ranking that highlights tourist destinations implementing innovative and effective practices for more responsible and sustainable tourism.

The park is in the upper Juncal River basin, one of the main tributaries of the Aconcagua River. Its primary mission is to protect the Juncal watershed. The basin lies in the Valparaíso Region of central Chile (32° 53' S; 70° 08' W), between 2,000 and 5,000 m asl, covering approximately 220 km², of which the park occupies around 137.96 km² – roughly two-thirds of the basin. During the summer and in periods of low precipitation, this glacial system contributes up to 67% of the total flow of the Aconcagua River. It supplies drinking water to an estimated 1.5 million people across the basin, according to the Aconcagua Observatory of Socio-environmental Conflicts, and to approximately 200,000 people through the basin's rural water systems (APR).

The main boundaries of the park are the Juncal River to the west, the Republic of Argentina to the east, and the *Monos de Agua* stream to the south. It lies within the high Andean biogeographic province, recognized for its ecological uniqueness and low representation within Chile's national system of protected areas (Moreira-Muñoz & Troncoso 2014). The climate is dry and arid, with winter precipitation and high diurnal temperature variation, and the landscape includes shrublands, grasslands, rock outcrops, wetlands and glaciers (Zapararte et al. 2022). As shown in Figure 2, Parque Andino Juncal includes wetlands of significant ecological importance such as the *vegas* Los Nacimientos, Mardones and Canchitas, along with smaller ones like La Paz and La Roca. Associated with this, vegetation surveys show that there are around 200 plant species in wetlands and on slopes (Cádiz-Veliz & Muñoz 2025). The site is habitat for a significant group of fauna and flora, including endemic species such as the short-tailed snake (*Tachymenis chilensis*), as well as endangered species such as the matuasto (*Phymaturus flagellifer*) (RAMSAR 2010) and gato andino (*Leopardus jacobita*).

The RAMSAR site Parque Andino Juncal is the only protected area for Andean flora in the Aconcagua River basin and the mountain range of the Valparaíso region. The zonal vegetation is known as *Andean scrub* (Muñoz-Schick et al. 2000). This vegetation belt is distributed along the high slopes of the Andes Mountain range, from approximately 32 degrees to 35 degrees South, starting at an elevation of 2,000 m asl. It has been calculated that this belt is protected on only 2.4%

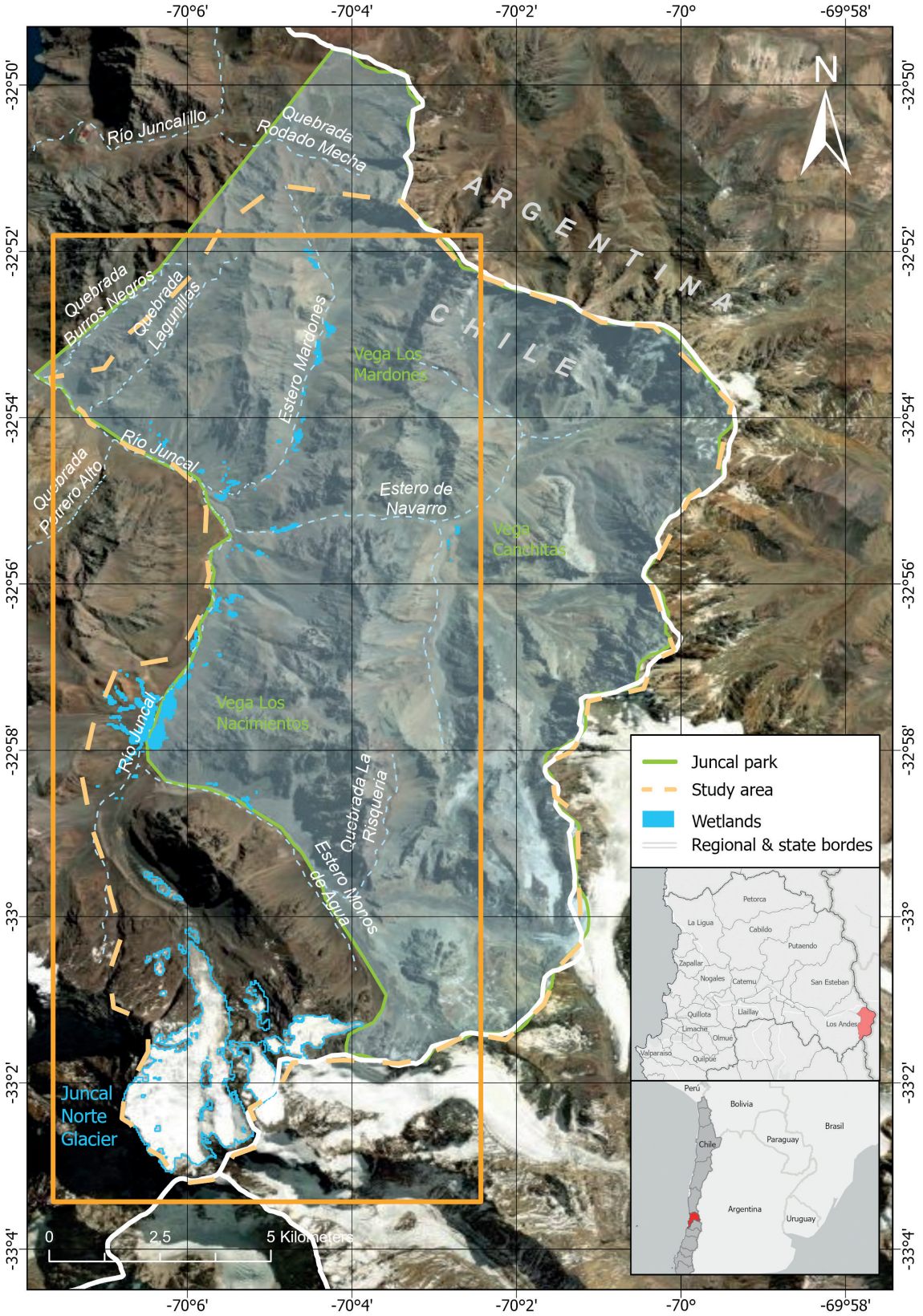


Figure 2 – Parque Andino Juncal, context map. The orange box outlines the excerpts shown in Figure 6. Data base: Esri World Imagery; https://gadm.org/. Created by Pablo Mansilla.

of its surface (Luebert & Pliscoff 2017). In addition to the mentioned dominant species, other characteristic species are *Mutisia sinuata* Cav., *Mutisia subulata*, *Rhodolirium montanum* Phil., and *Tropaeolum polyphyllum* Cav., among others. These species are visited by an assemblage of pollinators that includes native species of birds, bees, wasps, butterflies and beetles (Figure 3). Among plant species, there are some interesting cases



Figure 3 – Native and endemic plants and characteristic birds and pollinating insects of Parque Andino Juncal: a) Alstroemeria parvula Phil.; b) Mutisia sinuata Cav.; c) native bee Megachile semirufa Sichel; d) native jewel wasp (Chrysis sp.); e) periquito cordillerano, Bolborhynchus aurifrons Lesson; f) Tropaeolum polyphyllum Cav.; g) Rhodolirium montanum Phil.; h) Chuquiraga oppositifolia D.Don. © Moreira Muñoz

of restricted endemism that are at the same time considered as endangered, such as *Ivania juncalensis Al-Shehbaz* (Cádiz-Véliz et al. 2022) and *Alstroemeria parvula Phil* (Muñoz-Schick et al. 2011).

The Parque Andino Juncal project combines integrated conservation measures, aligned with the guidelines of the IUCN, with ecological tourism. They apply a passive restoration strategy, that involves the recovery of environments through the elimination of agents of disturbance, with the aim that the ecosystems will recover naturally. Tourism serves as the primary source of funding, supporting the salaries of park rangers and ongoing maintenance tasks. Parque Andino Juncal remains open from approximately October to April; during the rest of the year, the road and the visitor centre are closed because of winter conditions.

In line with the IUCN approach, the park has established zoning between recovery areas and buffer



Figure 4 – Vegetation types, wildlife and wetland landscape at Juncal Andean Park: a) Senecio bonariensis; b) Calceolaria biflora and Werneria pygmaea; c) Hordeun comosum; d) Tropaeolum polyphyllum. © Calderón Archina and Leandro Alvarez 2025

zones. The recovery areas include exclusion zones located near the wetlands, designated for passive restoration, where high-Andean wetland vegetation (locally known as *vegas,* see Figure 1) are dominated by species such as we show in Figure 3 and *Carex gayana*. This conservation approach involves physical barriers that restrict access, thereby promoting vegetation regrowth after decades of grazing-related impacts. The buffer zones are concentrated along the main trail leading to the glacier viewpoint and the designated camping area. Notably, a daily visitor cap of no more than one hundred people has been implemented to help control and minimize ecological impact.

Recently literature showed the resilience capacity of wetlands to respond to and recover from various anthropogenic and environmental disturbances (Jacob et al. 2025). Some of these studies highlighted that designing specific strategies, as we describe, helps to build and improve resilience in complex socio-ecological systems such as wetlands and enhances biodiversity conservation (Kopprio et a.2014; Mustonen & Kontkanen 2019; Reid & Shafiqul Alam 2017).

Geohistorical context

"*The place is full of human history*", says Tomás, the administrative coordinator of Parque Andino Juncal. His words encapsulate thousands of years of human presence in the Juncal Valley, beginning with archaeological settlements dating back at least 10,000 years (Planella & Stehberg 1997). However, the site only became more visible and accessible toward the end of the nineteenth century, when the entrepreneurial Clark brothers acquired a concession to construct the ambitious Trans-Andean Railway. This railway connected the cities of Los Andes, Chile and Mendoza, Argentina. It was inaugurated in 1910 and operated until 1984, with intermittent closures due to adverse mountain weather conditions.

In 1911, the British business family Kenrick Lyon purchased the land now comprising the park for commercial purposes, as the railway line passed directly through it. Near the property there operated the Juncal railway station, later renamed Hermanos Clark station, which served as a major operations hub (Lacoste 2013). In July 1984, a landslide destroyed the Chilean



Figure 5 – Juncal Norte Glacier. © Calderón Archina 2025

section of the railway (Urzua 2015). From that point until the early twenty-first century, the land now constituting the park experienced various land uses, including mining and livestock grazing. Specifically, within the current park grounds, a gypsum mine and later a brick factory were established. Today, the former brick kiln functions as a base camp for visitors.

Regarding livestock activities, these represent a longstanding practice dating back to the colonial era, sustained for centuries due to high demand for cattle from Cuyo in Chile's central valley (Michieli 1994; Escolar 1996). The cross-border livestock trade was primarily managed by *baqueanos* and *arrieros*, known for their expertise in mountain navigation and animal husbandry (Escolar 1996). *Baqueanos*, traditionally local scouts or trackers, are highly skilled in navigating rugged terrains, while *arrieros* are muleteers or herders who lead livestock caravans across long Andean routes. A central component of their practice is transhumance, still maintained today, involving the seasonal movement of herds from high-altitude grazing areas in summer (*veranadas*) to lower elevations in winter (*invernadas*), and back again. This cyclical migration allows herders to exploit forage that grows at different altitudes, especially in *vegas* situated near meltwater streams (Hevilla & Molina 2010). For this reason, the wetlands of the Juncal Valley have long been essential summer grazing grounds. Over centuries, *arrieros* have become the most historically established seasonal inhabitants of these inter-Andean valleys.

Grazing in the *vegas* was one of the main challenges the park faced when establishing itself as a protected area. In 2003, when Catherine Kenrick Lyon inherited the property, she initiated substantial changes in land management – a process that took several years. Among the most pressing obstacles were livestock grazing and hunting. "*You could not just tell the arrieros not to pass. For them, this is mountain land, and they have always brought their animals here… It was the same with the military and hunters"*, explains Martín, head ranger at the park since 2017. Today, thanks to the dialogue built with *arrieros* over the years, a good relationship has been maintained. This agreement allows them to continue bringing cattle to graze near the park during summer, ensuring that the animals do not enter the protected reserve. In some sections, the boundary is marked by fencing, while in others, it is defined by natural features such as the river. When livestock occasionally cross into the reserve, *arrieros* retrieve them promptly. Park staff not only note the respectful collaboration but also highlight the *arrieros*' extensive knowledge of the mountain environment.

Effects of Climate Change on the Juncal Norte Glacier

The results of this study show that multiple processes operate simultaneously at different scales, shaping territorial patterns of degradation (glacial loss) and regeneration (*vega* expansion) in high mountain environments. Across the entirety of Parque Andino Juncal, there has been a sustained 53% decrease in ice cover and a significant 49% expansion of wetlands, particularly in the Los Nacimientos *vega*, which has doubled in surface area with a 58% increase. Specifically, Juncal Norte Glacier (Figure 5) has undergone a sustained 34% reduction in surface area, consistent with previous studies (DGA 2022). At the same time, new pressures have emerged due to the expansion of mining activity at the national level and the resulting social conflicts.

The analysis of glaciers and high Andean wetlands (*vegas*) was conducted using Landsat sensor imagery (TM, ETM+ and OLI) processed via Google Earth Engine – GEE (Gorelick et al. 2017; Amani et al. 2020). For the period 1986–2025, cloud-free mosaics were generated for the austral summer months (December–March), minimizing interference from seasonal snow. Spectral indices were applied to these image composites: NDVI (Normalized Difference Vegetation Index) to identify active vegetation (threshold >0.35) and NDSI (Normalized Difference Snow Index) to delineate glaciers and ice bodies (threshold >0.65) (Marcosig & Liaudat 2021; Zalazar 2023). The resulting layers were vectorized using QGIS 3.0 to quantify surface changes, considering ENSO influence (NOAA data).

Significant changes were recorded in glacial and wetland cover in Parque Andino Juncal between 1986 and 2025. Overall, glaciers progressively lost surface area, while wetlands expanded (Figure 5 & 7). Juncal Norte Glacier experienced a 34% decrease in surface area (from 11.5 km² to 7.6 km²), while the Los Nacimientos *vega* increased in area by 73% (from 43.1 ha to 74.8 ha) (Figure 6). The retreat of Juncal Norte Glacier was pre-

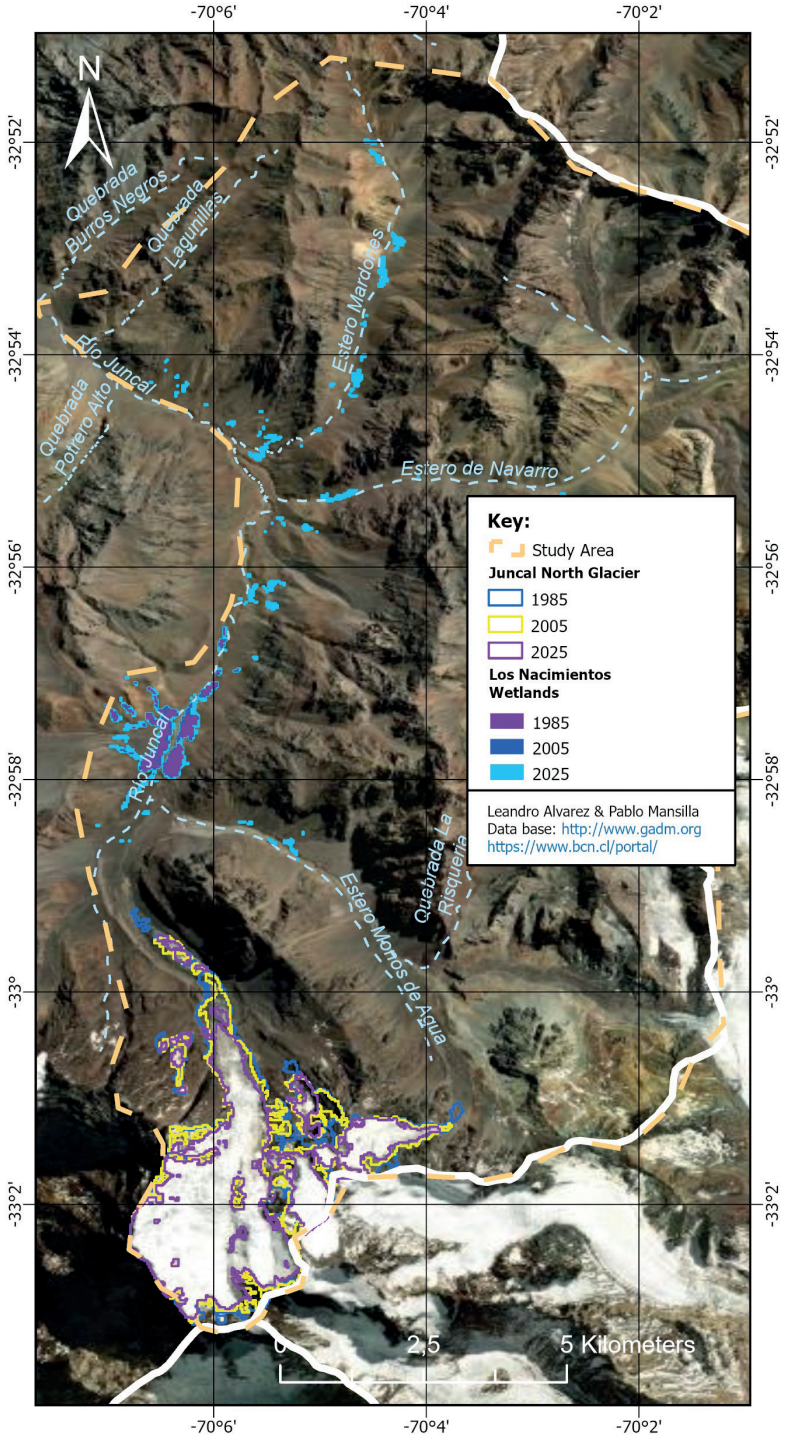


Figure 6 – Spatial dynamics of Juncal Norte Glacier and Los Nacimientos wetlands from 1985 to 2025 within Parque Andino Juncal, Valparaíso Region, Chile. See Figure 2 for the overview of the area.

viously documented by DGA (2022), which reported a 30% loss in glacial mass. These studies also note substantial variability in the advance and retreat dynamics of glaciers in the area. Our findings align with those of Zalazar (2023), who suggests that glacier retreat may increase local water availability, promoting the expansion of adjacent wetlands, which helps explain the sustained growth of Los Nacimientos.

During the initial period (1986–2005), the expansion of *vegas* was closely linked to El Niño events, which brought increased winter precipitation (Marcosig & Liaudat 2021). However, between 2005 and 2025, following the establishment of the protected area, this pattern changed: *Vegas* continued to expand even during La Niña phases, such as that of 2021–2022. This shift is associated both with glacial retreat and with active conservation measures, such as livestock exclusion, which have supported wetland recovery. According to Catherine Kenrick Lyon, maximum temperatures in the park reached 28 °C in January 2025, indicating extreme conditions that also impact these ecosystems. Within this context, the 2023 El Niño event triggered a marked resurgence in *vega* surface area following the previous drought, highlight-

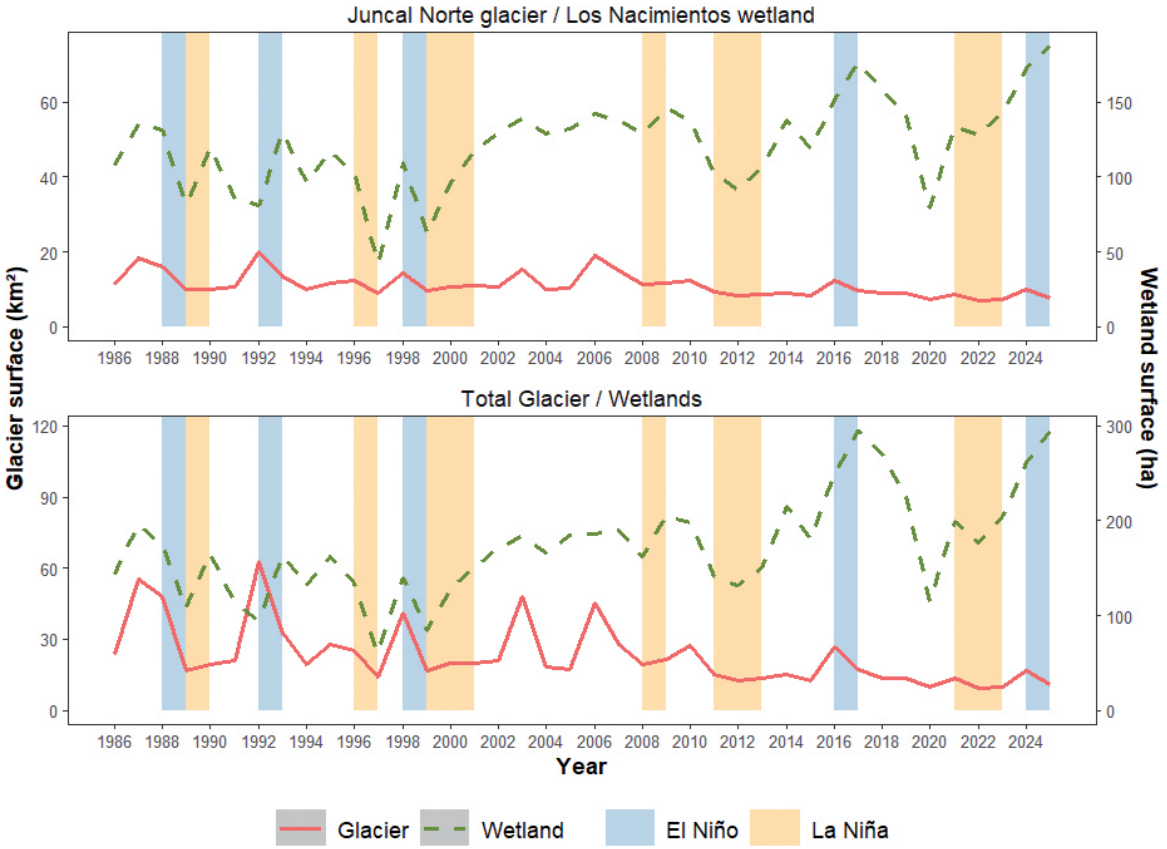


Figure 7 – Time series showing the evolution of glaciers, ice bodies and wetlands (above), and specifically the Juncal Norte Glacier and Los Nacimientos vega (below), for the period 1986–2025. Data source: source: https://ggweather.com/enso/oni.htm / Layers Processing: Leandro Alvarez

ing increased ecosystem resilience as a result of park management practices.

Conflicts over mining extractivism

Since 2017, the mining company Nutrex SpA has sought to establish operations in the Juncal Valley. It began with an exploration project covering approximately 8,000 hectares adjacent to Parque Andino Juncal. In 2023, the company submitted a request for an exploitation concession over the conservation area. The owners of the park appealed the request through legal channels, but the court ruled in favor of the company's continued operations. Faced with the possibility of active concessions and subsequent exploratory drilling, various sectors of civil society mobilized publicly to denounce the damage such activity would cause. The mining claims are located directly on high Andean wetlands and glacier surfaces (Fundación Plantae 2024), which would disrupt watercourses, alter wetland functioning and impact endemic and endangered species such as the Andean cat (*Leopardus jacobita*). Additionally, the project would undermine long-standing biocultural practices, including traditional hiking routes.

At the beginning of 2024, widespread demonstrations took place both in major cities of the Valparaíso Region and within Juncal itself in response to the imminent installation of the project (see Figure 8). A large group of activists and residents camped for two weeks at the entrance to the park to block access to the mining personnel. The encampment brought together rural inhabitants, environmentalists, Indigenous communities and academics. Also, present was the *Defensa Akonkawa Coordinating Committee*, a coalition of over 20 socio-environmental initiatives and collectives active in the Aconcagua Basin. Due to the mobilization and resulting public pressure, the company's personnel temporarily withdrew from entering the park. Nevertheless, the project remains active and could resume at any time. Under the current legal framework, mining claims can now be formalized through Geographic Information Systems without the need for physical presence on the land. This may be seen as a strategy to reduce or bypass social mobilization. Even so, the reserve's owners, valley residents and activists remain on high alert in defense of Parque Andino Juncal. It is important to say that, in Chile, legislation establishes that mining concessions are independent from surface land ownership, and in cases of conflict between surface and subsurface uses, mining activity takes precedence.

Private management of High Andean Wetlands in a context of glacial retreat

In a global context of glacial retreat and adverse climatic conditions, the high Andean wetlands of Parque Andino Juncal have undergone significant recovery in recent decades. Notably, Juncal Norte Glacier experienced a sustained 34% reduction in surface area between 1986 and 2025, while the Los Nacimientos *vega* expanded – even during drought years linked to La Niña events – suggesting that resilience mechanisms have been strengthened through protected area management. This case illustrates how private conservation-oriented management can enhance ecosystem resilience under challenging climate scenarios.

A central factor in this recovery has been the exclusion of livestock, alongside active habitat monitoring and protection, which has restored the role of wetlands as ecological refuges while maintaining essential functions such as water provision and carbon sequestration. Additionally, this adaptive management model has supported the return and persistence of emblematic native species such as the Andean cat (*Leopardus jacobita*), puma (*Puma concolor*) and guanaco (*Lama guanicoe*), whose presence has been documented with increasing frequency in recent years.

This case demonstrates that, even on a small scale, APPs can play a crucial role in conserving fragile ecosystems in the face of climate change. The positive outcomes of such management are evident not only in the ecological recovery of wetlands, but also in their strengthened capacity to respond to extreme climate disturbances recently observed. In this way, Parque Andino Juncal serves as a replicable model for adaptive conservation initiatives in other sectors of the Andean cordillera.

It is important to emphasize the park's positive effects and the urgent need to support conservation initiatives in vulnerable ecosystems – especially given the mining company's intent to operate near Juncal Norte Glacier. Although social mobilization has so far prevented mining personnel from accessing the site, the company holds a judicial mandate to proceed. This would directly impact high mountain ecosystems, including *vegas* and stream systems, as well as the plant and animal species that inhabit them – such as the endangered Andean cat. Thanks to the collective resistance of various social actors defending the Juncal River and the Aconcagua Valley – including a two-week encampment at the park entrance and additional actions in Viña del Mar and other urban centres – the mining project was temporarily halted. However, the state of alert continues, as the project may resume once the mining claim is formalized, and currently no measure exists to prevent it apart from the social pressure that began one year ago.



Figure 8 – Park entrance and camping area during the protest in 2024. © Calderón Archina 2025

Founding

ANID ANILLOS ATE230072 Climatic Pluriverses.

ANID FONDECYT nº1252155 Decolonial Animal Geographies from the South: Multi-Species Trajectories Through the Andes in the Context of Environmental Change.

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Authors

Aldana Calderón-Archina[1]

is an anthropologist with a PhD in anthropological sciences from the Universidad Nacional de Córdoba. She is a postdoctoral researcher in the Pluriversos Climáticos Project at PUCV in Chile and a professor at the Universidad Nacional de Cuyo in Argentina. From an ethnographic perspective, she explores the relationships between human and non-human groups and the environment. E-mail: aldana.calderon@pucv.cl

Leandro Manuel Alvarez[2]

is an ecologist and professional adjunct at IANIGLA-CONICET with a master's degree in environment and sustainable development. He specialises in GIS, remote sensing and ecological monitoring. He teaches conservation, coordinates fieldwork campaigns and delivers postgraduate courses on GIS applications for solving environmental problems and restoration. E-mail: lalvarez@mendoza-conicet.gob.ar

Andrés Moreira-Muñoz[1]

is a professor at the Pontifical Catholic University of Valparaíso (Institute of Geography). He has a Doctorate in Natural Sciences from the University of Erlangen-Nürnberg in Germany and a degree in Geography from the Pontifical Catholic University of Chile. His research focuses on the botanical geography of vascular plants in Chile and the Andes. E-mail: andres.moreira@pucv.cl

Pablo Mansilla Quiñones[1]

is a professor at the Pontifical Catholic University of Valparaíso (Institute of Geography), where he is involved in teaching, research and community participation in the fields of social and Latin American geography. He is the director of the Pluriversos Climáticos project (ANID ATE230072). E-mail: pablo.mansilla@pucv.cl

[1] Pontificia Universidad Católica de Valparaíso, Chile (PUCV).
[2] Consejo Nacional de Investigaciones Científicas y Técnicas – Instituto Argentino de Nivología, Glaciología y Ciencias Ambientales. Mendoza, Argentina (CONICET - IANIGLA).

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Trade-off management: a tool to create universal value in landscape development

Maria Thaís Affonso

Keywords: Biosphere, Entlebuch, trade-off, landscape, land use, conservation, agriculture, value distribution, sustainable development

Abstract

Managing multiple interests in landscape and land use management is an element critical to sustainable economic and social development. Structuring and visualizing conflicting interests in a such a way as to drive the constructive engagement of multiple stakeholders is, however, a difficult task. With the aim of addressing this challenge, an initial concept on how to benchmark different landscape management models based on their ability to minimize trade-offs was presented in 2020 at the Swiss Landscape Congress, using the UNESCO Biosphere Entlebuch (UBE) as case example. During 2021–2022 the author further developed the methodology and framework to assess trade-offs, updating and complementing the UBE characterization with new data and insights. This paper describes the results and conclusions of this deep dive work.

The UBE exercise indicated that since its creation there has been a simultaneous improvement of various social, economic and environmental aspects at the biosphere region, with a visible minimization of trade-offs and a fair distribution of the value created. It remains open how many of these positive developments can exclusively be attributed to the UBE model. Comparisons with similar areas are therefore key to allowing a better interpretation of mechanisms and achievements and this paper is an invitation to other parks to participate in a similar exercise.

Profile

Protected area

UNESCO Biosphere

Entlebuch

Mountain range

Alpes, Switzerland

Introduction

Involving aspects of physical and human perception, the *landscape* represents an essential component of people's surroundings (cf. European Landscape Convention 2000). At the same time, landscapes are a result of deliberate choices made by multiple individual actors who often act in a unilateral and siloed way. As the conservation and regeneration of natural resources come increasingly into focus, coordination among multiple stakeholder groups becomes essential and increasing attention is dedicated better to understand and address the various, often conflicting interests that are involved in land use management (Bradford & D'Amato 2012; Sylla et al. 2020; Vogel et al. 2024).

The central challenge therefore lies in managing and mitigating these conflicts in order to guarantee distributed value creation. Yet, bringing important trade-offs to the surface in such a concrete way and at an adequate level of granularity so as to drive constructive dialogue among decision makers is not straightforward, especially considering the complex data environment.

The methodological approach proposed here intends to tackle this challenge by means of a structured and practice-oriented framework that facilitates the identification and characterization of conflicting interests and associated trade-offs. The ultimate goal is to equip decision makers with tools to decide consciously on the best combination of actions and interventions to create shared value.

The award-winning UNESCO Biosphere Entlebuch (UBE) has been used as a case study to test the concept and applicability of the proposed methodology.

The methodology and framework proposed to assess trade-offs

In 2020 an embryonic idea of how to assess different landscape management approaches based on their ability to minimize trade-offs was presented as a joint research effort at the Swiss Landscape Congress (Affonso et al. 2020). It had been built on the hypothesis that the better the trade-offs are managed, the more successful the drive for resilient regional development will prove and the more egalitarian the value created among different segments of business and society. Building on this preliminary work, the author has further elaborated the methodology and enhanced the trade-off analysis with a monetary quantification. The UBE case, pre-populated in 2020, has been complemented with new indicators, updated information and new insights from local research, in close coordination and exchange with Florian Knaus and UBE stakeholders.

The proposed, so denominated *trade-off framework* offers a fit-for-purpose tool that connects the main transformational levers that constitute a landscape model with the actual impact observed in the field, and

1 Mapping the key components of a landscape unit	2 Assessing impact	3 Characterizing the trade-off pairs	4 Critical analysis and interpretation
• Strategic pillars • Development pathways • Trade-off pairs	• Systemic changes • Front-end impact	• Trade-off intensity • Benefit distribution based on monetary value	• Minimizing trade-offs • Creating shared value

Figure 1 – Trade-off framework.

it is applicable to landscape units with discrete physical boundaries and an established development plan (e.g. a natural reserve, a tourism region, an energy park, etc.). The framework is composed of four main steps, see also Figure 1:

1) Mapping the key components of a landscape unit and identifying trade-offs, by describing the essence and the key pathways for transformation embedded in the design or in the development plan of a given landscape unit. By complementing this assessment with interviews with key local stakeholders, the main conflicting interests are identified and a set of key trade-off pairs is identified.

2) Assessing the impact of implementation based on measurable indicators, by identifying and creating a historical series of representative indicators that are directly measured. The impact is represented as the percentage variation of each indicator compared to a baseline, ideally covering the timeframe between the present state and the start of the project's implementation. The indicators are analysed from two perspectives:

Systemic changes of socio-economic fundamentals, equivalent to *leading indicators* clustered into: i) access to basic services (e.g. education, health care, housing, mobility and connectivity; ii) sectorial productivity (e.g. manpower-, land- and animal productivity; practice intensification); iii) business-supportive environment (e.g. business-related infrastructure, job creation, sectoral investments, public / private interaction, regulations).

Front-end impact, equivalent to *lagging indicators* and clustered into: i) natural resources and biodiversity; ii) human well-being; iii) local economy; iv) local attractiveness; v) culture and identity.

3) Characterizing the trade-off pairs, composed of two complementary analyses:

Trade-off Intensity: calculated based on measurable indicators and by trade-off pair, it is defined as the distance to the line of benefit equivalence (Bradford 2012). The main objective is to identify areas of attrition.

Benefit distribution based on monetary value: assessed by stakeholder group, it reflects the perceived benefit or harm from the perspective of each stakeholder category, associating the temporal change of key indicators with a monetary gain or loss over the same period. The main objective is to identify if the value generated has been fairly distributed among the multiple stakeholder groups and / or economic sectors.

4) Critical analysis and interpretation, based on the effectiveness in minimizing trade-offs and in creating shared value.

Results: The UNESCO Biosphere Entlebuch (UBE) case example

Mapping the key components of a landscape unit and identifying trade-offs

UBE characterization and key trade-offs

The UBE encompasses an area of 395 km² at the valley of the *Kleinen Emmen* river between Bern and Lucerne, in Switzerland's alpine region (Figure 2). It includes 7 communes and 17,000 inhabitants, with ag-

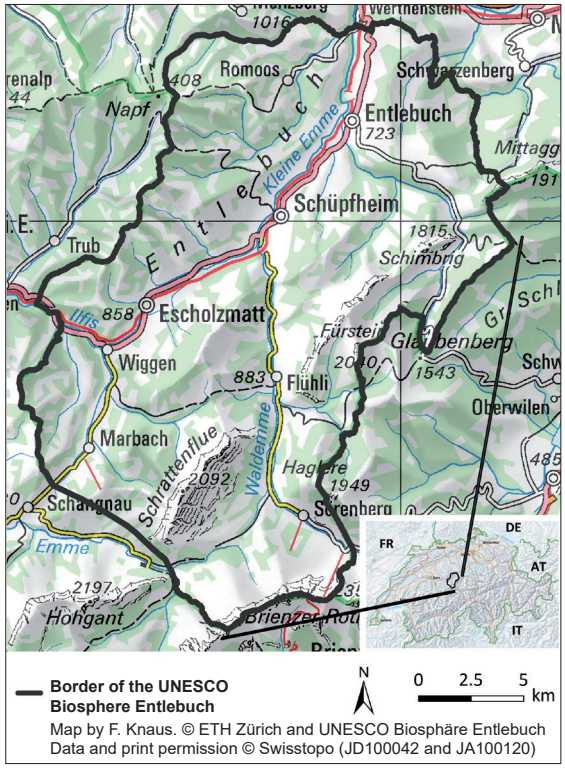


Figure 2 – UBE geographic situation. Data source: UBE and Swisstopo.

Headlines of economic model	Key systemic changes (transformational levers)	Categories of front-end impact	Trade-off pairs
• Premium products • Regional value chain • High value tourism • Differentiation through multi branding and certification of origin	• Improvement of public transport: network and schedule • Tourism infrastructure • Higher Education, support to local research • Higher productivity in livestock keeping • Change of animal portfolio in livestock • Professional and coordinated marketing	• Natural resources and biodiversity – Waste management – Air quality – Soil & water quality – Natural habitats – Fauna and flora biodiversity – Land use and landscape preservation • Human well being – Economic sustainability – Literacy • Attractiveness – For people – For business • Local economy – Tourism & services – Agribusiness – General	• Agribusiness vs Conservation • Tourism vs Conservation • Rural vs Urban development • Functionality vs Heritage

Figure 3 – Overview of the key components of the UBE model.

riculture (mainly livestock) and tourism being the two main pillars of the local economy. The region obtained the designation as a UNESCO Biosphere Reserve in 2001 as a response to national top-down peatland conservation activities in the late 1990s during which large parts of the region were set under conservation. Since then, it has tried to integrate conservation and regional development in a participative and integrative fashion.

The overarching UBE concept consists in leveraging its natural and cultural landscape as an instrument for sustainable regional development, following the premise of *protecting by using*. It approaches conservation with a broad scope, covering natural, as well as semi-natural and culturally influenced landscapes, explicitly targeting the equilibrium between environmental, social and economic aspects, with particular attention to the needs of the local population. It is backed by 3 leading strategic pillars: Conservation; Economic Development; and Education and Research (REP UBE 2012).

This comprehensive *sustainability* principle is underpinned by key development pathways adapted to the local conditions and covering all sectors of the economy (UNESCO Biosphäre Entlebuch 2017), i. e.:

- strengthening the regional production chain, building on circular resource management and elevating local products to a premium segment combining tradition + quality + provenance;
- boosting traditional, family-driven agricultural businesses through product improvement and the creation of side activities that generate additional sources of income;
- leveraging the natural landscape to amplify the value created by leisure and tourism, promoting tourism close to nature, with special attention to stimulating long-term visitors;
- extracting value from a region-specific, multi-brand strategy reinforcing sustainability and certification of origin;
- leveraging research and education to multiply local professional opportunities and increase sense of ownership of local population.

These go hand-in-hand with a thought-through mobility concept based on effective road and public transport infrastructure to facilitate access from – and to – regional centres, as well as on slow and low noise mobility solutions within UBE boundaries, prioritizing alternative power systems derived from local renewable energy sources (UNESCO Biosphäre Entlebuch 2012).

Based on a critical analysis of the UBE model and on interviews with people that were part of the implementation process, four main trade-off pairs have been defined: 1) agribusiness vs conservation; 2) tourism vs conservation; 3) rural vs urban development; 4) functionality vs heritage.

Assessing the impact of implementation based on measurable indicators

An extensive series of indicators directly or indirectly associated with the UBE strategic pillars and pathways have been assessed, covering the period between 2006 and 2019 (for which most of the recurring statistics and non-recurring survey data are simultaneously available) and merging relevant data from various sectors and on various topics. Statistics associated with demographics and business have been gathered in the federal and cantonal websites for statistics, in which UBE is described as an individual analytical unit. These have been complemented by UBE research and biodiversity studies, local opinion surveys and inter-

Category	Subcategory	Indicators and metric	–50 0 50 150%
Natural resources and biodiversity	Waste management/ reduction	Waste subject to recycling (as % total waste) Household waste per inhabitant (kg/yr)	
	Air quality	NH_3 gas in the air (m^3) Daily cars to/from main commune Schüpfheim (#)	
	Soil & water quality	Rate of fertilized area (% of agricultural area) Nitrate in water (mg/m^3)	
	Natural habitats	Forest reserves area and wooded land (hectares) BFF area, ecological protected (hectares)	
	Fauna & flora biodiversity	Birds' indicator species (#) Butterflies' indicator species (#)	
	Land use & landscape preservation	Urban area and Agricultural area (hectares) Individual and high-stem trees (#)	
Human well-being	Economic sustainability	Employment rate (% population in working age) Taxable income of individuals (SFr) and evolution vs canton's average (% pts)	
	Literacy	Rate professional education (% population) & evolution vs canton's average (% pts)	
Attractiveness	For people	Local population 15–24 yrs age (# people) Net population increase due to migration (#): average 5 yrs & change in the period Commuters living at UBE and working elsewhere (#)	
	For business	New companies established (#)	
Local economy	Tourism & services	Number of summer tourists (#) and Overnight stays (#) Number of hospitality businesses (#) Employment of sector 3 (# people)	
	Agribusiness	Employment of sector 1: Total & in agriculture (# people) Agriculture businesses (#) Revenues of premium agricultural products (SFr) Payments associated to BFF (ecological protected) area (SFr)	
	General	Taxable income of companies (SFr)	

Figure 4 – Summary of UBE front-end impact indicators. Bars represent the relative magnitude of variance in %, calculated as the average change of individual indicators in the period, predominantly 2005–2018. Natural habitats: indicative range above 100%, driven by very strong increase of forest reserve area, partially distorting the average value. Data source: Federal (BFS Bern) and Cantonal (LUSTAT Luzern) Office for Statistics; Knaus 2012, 2013, 2017; Hugi 2015; von Lindern et al. 2019; von Lindern 2020; Wiesli et al. 2020; Seitler et al. 2020. SFr = Swiss Francs, BFF = biodiversity promotion areas

views with local business stakeholders (Knaus 2012, 2013, 2017; Hugi 2015; von Lindern et al. 2019; von Lindern 2020; Wiesli et al. 2020; Seitler et al. 2020).

a) Systemic change of socio-economic fundamentals: The indicators of systemic change focused on the key aspects of transformation described in the UBE plan, i.e. mobility and physical connectivity; operational productivity and practice intensification in agriculture; business-supportive investments in basic and tourism infrastructure; the creation of new jobs; the production of scientific and academic work.

The analysis indicated that, consistent with the UBE plan, there was a significant improvement in agricultural-related productivity (animal husbandry) and a visible expansion of the transport infrastructure, supported by a continued flow of investments and a multiplication of local research activity.

b) Front-end impact: The indicators of front-end impact have been selected to best reflect the impact of the UBE strategic pillars and associated initiatives (e.g. multi-brand strategy, intensified summer tourism, premium products) and have been clustered into the following categories i) natural resources and biodiversity; ii) human well-being; iii) local economy; iv) local attractiveness. The analysis indicated that there was a predominant positive impact in almost all the parameters and categories analysed. Figure 4 shows a consolidated view of the front-end indicators as an illustrative example of the assessment; more details can be consulted upon request.

Characterizing the trade-off pairs

a) Trade-off intensity was calculated based on measurable indicators that most directly influence or compete with each other within a trade-off pair, as follows:

1. *agribusiness vs conservation*: indicators related to the land use of forests and agriculture; to the intensity of agricultural operations (e.g. fertilization; animal intensity) and their potential impact in nature (e.g. pollution in water and air; biodiversity); to the revenues of premium products; and to the intensity of subsidies relating to sustainable agricultural practices;
2. *tourism vs conservation*: the focus was on the intensity of summer tourism businesses, tourist-related traffic and waste vs changes in the shape and coverage of the protected area and related species;
3. *urban vs rural development*: the focus was on land use, the number of businesses and the employment rates associated with each category.

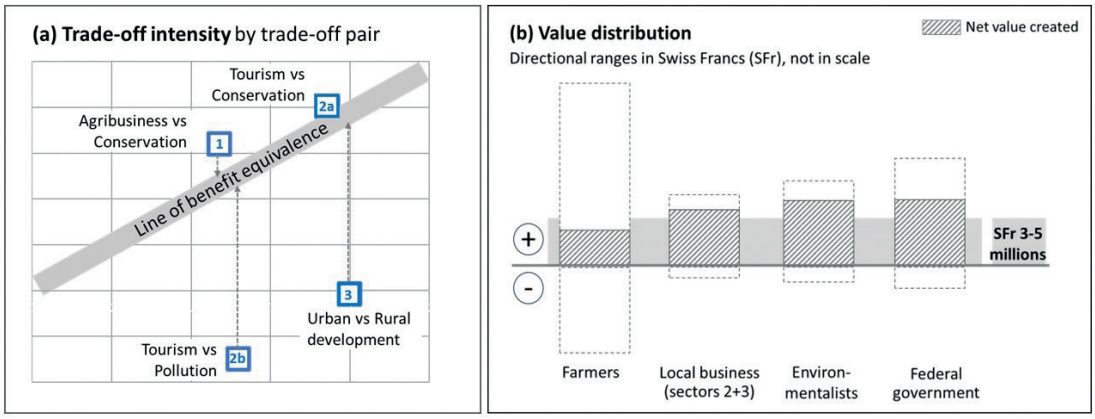


Figure 5 – Summary of the UBE trade-off analysis: (a) Trade-off intensity. Methodology based on Bradford 2012; (b) Monetary value distribution by stakeholder group. Comparative analysis based on directional ranges. Data source: see Figure 4. SFr = Swiss Francs

The trade-off *functionality vs heritage* has not been analysed due to the lack of representative indicators. Instead, the impact of tourism on pollution was deep-dived as a supplementary analysis of the *tourism vs conservation* trade-off.

The analysis indicated a low trade-off intensity (low attrition) between conservation, agriculture and tourism (Figure 5, trade-offs 1 and 2a), with the positive development of multiple aspects underlying both trade-off pairs, despite indications of worsening pollution associated with tourism (Figure 5, trade-off 2b). On the other hand, there are signs of an uneven development between the rural and urban environment, mainly concentrated in urban activity (Figure 5, trade-off 3).

b) Benefit distribution based on monetary value: At the UBE, four main stakeholder groups have been selected for value concentration analysis, for which an individualized rationale for the monetary calculation has been established as follows:

- *farmers* (sector 1): net revenues resulting from the positive impact of the premium price of UBE-branded products and higher operational productivity, and the negative impact of the closure of operations, loss of agricultural land and livestock losses on account of wild animals;
- *local business holders* (sectors 2 & 3): net balance of the positive impact of higher tourism and services revenues due to *green tourism* as well as the sustainable exploration of areas of conservation, and annual commune contributions to UBE maintenance;
- *environmentalists*: equivalent economic value of the net CO_2eq storage and emissions balance derived from the positive effect of less agricultural land, increased tree density and the shift to smaller animal portfolios, and the negative impact of increased tourism-related traffic and waste;
- *federal government*: net revenues resulting from the positive impact of higher taxable income and a lower social cost burden due to positive economic development, as well as lower risks of natural disasters, and the negative impact of the subsidy payments associated to biodiversity promotion areas (BFF) and the annual federal contribution to UBE maintenance.

The analysis indicated that value of the order of magnitude of at least mid-single digit millions of Swiss Francs has been simultaneously created for each of the stakeholder categories over the considered time frame, with no major disproportionate concentrations of benefits or burdens.

Critical analysis and interpretation – UBE case study interpretation and concluding remarks

In the 1990s the region of Entlebuch was characterized by a disadvantaged position when compared with other Swiss regions in terms of economic power and attractiveness. A significant gap was perceived in the provision of basic infrastructure and retaining the young population was seen as a major challenge (Wicki & Kaufmann 2003). The analysis indicates that during the last 10 to 15 years there has been a simultaneous improvement of multiple social, economic and environmental aspects, paired with a relative improvement compared to the canton's averages, reflecting a successful implementation of the transformational drivers embedded in the UBE model. UBE has put forward a successful regional development concept, whereby competing sectors support and complement each other, and universal value has been created and fairly distributed across the various economic sectors. Critical trade-offs were minimized or eliminated, most visibly between agriculture and conservation. The monetary evaluation of trade-offs indicates that significant and equitable value has been created in all economic sectors, despite the reduction of the regional agribusiness footprint. The drop in livestock area and operations has been compensated by productivity increases and by the shift towards premium products and smaller animals. Conservation has been transformed into a key universal value creator, foster-

ing high value segments of business and customers inside the different sectors, serving therefore as a key driver for a more egalitarian value distribution across segments. In addition, the Biosphere has fostered the unification of the region, operating today synergistically as a tourism cluster, nature conservation agency and regional production chain, as well as acting as a pool of attraction, innovation and labour for the young population.

It is recognized that many aspects analysed here are not exclusively and casually related to the UBE model but also influenced by national and cantonal regulations. It is likewise acknowledged that trade-offs between sectors have been partially mitigated by federal intervention.

It is nevertheless considered that UBE was able to amplify the benefits of national sectorial policies, this success being attributed to a mix of thought-through concepts linking business and nature, and a superior governance archetype effectively engaging with various actors and constructively tackling major conflicts in a pro-active manner.

The UBE case study endorses the underlying belief that the success of a landscape model is directly associated with the ability to reduce trade-offs. It also indicates that managing the landscape through trade-off mitigation implies that a central coordination is required to engage with all stakeholders and siloes, aiming to steer / align their approaches and activities towards a common goal. Benchmarking with other protected regions and parks will be required to elaborate this thesis better and gain more insights in the functioning of parks and other socio-economic contexts.

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Author

Maria T. Affonso

Advisor Strategy, Innovation and Sustainability, Agribusiness, Basel, Switzerland. E-mail: dr.affonso@icloud.com

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Landscape evolution – insights from the Research Symposium SNP+ 2025

Stefanie Gubler, Roger Keller, Angelika Abderhalden, Linda M. Feichtinger, Thomas Rempfler & Simon Aeschbacher

Keywords: landscape research, Swiss National Park, UNESCO Biosfera Engiadina Val Müstair, Biosfera Val Müstair, interdisciplinarity, long-term monitoring, perception, biodiversity, climate change

Abstract

The second edition of the Research Symposium SNP+, organized on the occasion of the 111th anniversary of the Swiss National Park (SNP), explored landscapes as a multidimensional phenomenon. Far from being a static physical structure, a landscape embodies ecological, cultural, historical, perceptual, and political dynamics. The symposium contributions highlighted ambiguities in landscape perception, the potential of landscape in mediating tensions between nature and society, and showcased a variety of approaches for investigation and research.
This article synthesizes key insights from the symposium, focusing on four topics: (1) landscape as a multidimensional experience, (2) contested use of landscape, (3) potential for up-scaling, and (4) methodological diversity in landscape research. Long-term datasets from the SNP underscore the critical importance of historical perspectives for understanding landscape evolution driven by different factors, from climate change to biodiversity loss. Ultimately, the symposium emphasized that research not only generates knowledge but also enables landscapes to act as bridges between disciplines, practices, and societies.

Profile

Protected area

Swiss National Park

Mountain range

Alpes, Switzerland



Figure 1 – Landscape in the lower Engadin. © Stefanie Gubler

Introduction

After the first successful Research Symposium SNP+ in 2023 (Gubler et al. 2024), the 111-year anniversary of the Swiss National Park (SNP) served as motivation to hold a second edition of the symposium focusing on the broader topic of landscape evolution. The symposium topic *Landscapes under the magnifying glass* was inspired by a comprehensive review of the SNP's photographic archives conducted on the occasion of the 111-year anniversary. This review examined a wide range of historical images that document the SNP's landscapes and their changes over time, systematically categorized by habitat type (meadows, forests, aquatic habitats, high altitudes, as well as man-made infrastructure). Based on a curated selection process, 56 historical photos were re-taken in 2023 and 2024 at the exact same locations. These so-called re-photographs, together with their historical counterparts, document the changes that have occurred in the landscape over the past century and invite us to reflect on these changes. The photo pairs highlight the dynamic nature of landscapes – whether changes were fast or almost absent – and provide a tangible entry point into wider questions about natural processes as well as the perception, use, and conservation of landscapes. Building on these photographs and the accompanying exhibition on display at the SNP Visitor Center in Zernez until March 2027, the second research symposium examined the topic of landscape and its changes from a research perspective (see Figure 1).

Thanks to the vision of those who founded the SNP in 1914, a long-term research tradition has been established there. Nature and all its processes were to be protected in the SNP and subject to investigation and monitoring: *"For science, the national park is an invaluable field of observation, unique in its kind due to the complete elimination of human interference with the natural balance"* (Schröter 1920: 5, translated from German by deepl.com). Over the years, extensive knowledge about how and why physical landscapes have or have not changed in the SNP has accumulated. For instance, from the very beginning, botanical observation sites had been established (e.g., Braun-Blanquet 1931), the first rock glacier measurements worldwide were taken (Chaix 1923), the meteorological station Buffalora was installed, forest (Burger 1950) and ungulate observation

(e.g., Baechler 1919) started, along with many other studies on plants, forest, and animals. In 2012, an adjacent regional nature park was established and in 2017 the area was designated as a UNESCO Biosphere Reserve: Thus, landscape research was further strengthened in the Engadin and Val Müstair valleys, with an expanded focus that encompasses not only the natural sciences but also the cultural and social dimensions of landscapes.

The second Research Symposium SNP+ started with a keynote on the understanding of landscape through language, which was followed by three sessions on landscape research in the social sciences, the natural sciences, and from the perspective of young researchers. In addition, seven posters were presented. The event ended with final reflections by the Swiss Academy of Sciences (Figure 2). With over 80 attendees from multiple scientific fields, the symposium provided a platform for interdisciplinary exchange and addressed the challenges of understanding landscapes in their physical, cultural, and perceptual dimensions. This article synthesizes the main themes and insights that emerged from the symposium.



Figure 2 – Jürg Pfister, Secretary General of the Swiss Academy of Sciences, reflecting on the outcomes of the Research Symposium SNP+ and the meaning of landscapes. © SNP/Hans Lozza

Landscape as a multidimensional experience

One of the central premises of the symposium was that landscape consists of and enables multi-perspectives and can be perceived by all senses, from sight to smell, sound, touch, and even taste. Landscapes provide the physical foundation for life and simultaneously give us space for living, working, recreation, culture, and commerce. Or, as defined by the European Landscape Convention, landscape is *"… an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors"* (European Landscape Convention 2020). Additionally, landscapes provide benefits or services to humans that are often not made explicit, such as a sense of identity and connectedness (Keller et al. 2022). The symposium aimed at examining these multiple facets of landscape research. Ross S. Purves from the University of Zurich presented landscapes as a *slippery concept:* landscapes are complex, layered, mutable, and strongly shaped by subjective experience (e.g., Purves et al. 2023; Wartmann & Purves 2018). Approaches used in the *Landscape monitoring Switzerland* (Wartmann et al. 2021), for instance, demonstrate that subjective perception (e.g., through sensory experience, attribution of meaning or cognitive processes; see also Koegst et al. 2023) is crucial for assessing the quality of a landscape and that this subjectivity can change the attribution of quality to landscape – even if the physical parameters of the assessed landscape remain unchanged. In addition, historical knowledge and land-use legacies as known, for instance, from the forest *God da Tamangur* (Bürgi & Lock 2024) influence current perceptions and acceptance of landscapes.

Temporal and spatial scales further enrich the landscape perspective. Research in the SNP region ranges from large-scale regional assessments (e.g., HABITALP; Lotz 2006) to the study of fine-grained landscape elements such as springs (von Fumetti & Abderhalden 2024). Small-scale features, like microfauna in springs or alpine pasture vegetation, may appear marginal yet hold long-term significance for landscape trajectories and history.

Contested use of landscape

Owing to the multidimensional character of landscapes, landscapes accommodate multiple, and at times competing, interests that may give rise to conflicts. The symposium's contributions examined how landscapes embody tensions between nature and culture, for instance in the historical use of forests as pastureland (e.g., Bürgi & Lock 2024), or between conservation and use. The ongoing debate about large carnivores, in Switzerland particularly wolves, provides a striking example. The wolf can symbolize wilderness for some visitors, evoke fear among affected local populations or tourists, and pose management challenges for policymakers (Gattiker & Timcke 2024), all while playing a crucial and acknowledged ecological role in the Alpine ecosystem. Taken together, these perspectives highlight landscapes as arenas of negotiation, in which diverse perceptions, emotions, and interests intersect and are contested. Rather than treating conflicts as contradictions, the symposium underscored the potential to view conflicts as opportunities for exploring diverse perspectives and land-use approaches, as was shown in a contribution on the acceptance of the bear in the Central Apennines in Italy (Mayer et al. 2023).

Environmental education emerged as a key strategy for fostering coexistence between culture and nature, as is frequently done through dedicated courses for students in the SNP region, organized by diverse research

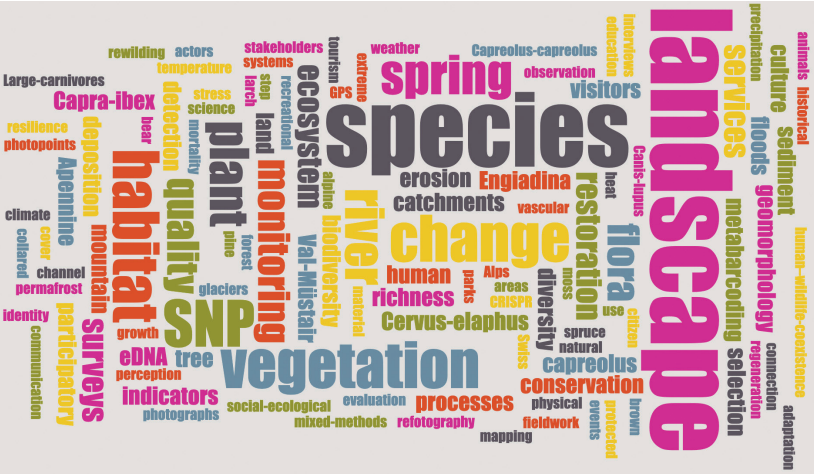


Figure 3 – Word cloud generated from the abstracts submitted to the research symposium. Word extraction and translation to English done by ChatGPT; Wordcloud generated by https://wordclouds.ethz.ch/.

institutions across Switzerland. By raising awareness, such initiatives can soften conflicts and enhance mutual understanding across different stakeholder groups (Buchecker et al. 2023). Ultimately, landscapes can be framed as societal negotiation processes, shaped by collective decisions about use, values, and identity.

The potential for up-scaling

A recurring theme at the symposium was the transformative potential of local initiatives and participatory approaches (Mayer et al. 2023). Projects such as regional nature parks demonstrate how grassroots efforts can spark off broader societal changes (Keller et al. 2022, 2025). For instance, as part of a ZHAW initiative of the Research Group for Wildlife Management supported by the Biosfera Val Müstair, measures such as the installation of bear-proof waste containers and electric fences to protect beehives were developed to prevent bears from becoming habituated to humans (Rempfler et al. 2009) and were later scaled up to other regions (e.g., Lower Engadin, Albula, Poschiavo), contributing to Val Müstair's continued absence of conflict-prone bears since the arrival of one of the first bears in Switzerland, i.e. JJ3. Moreover, emerging technologies hold considerable potential to both scale up landscape research and provide non-invasive monitoring opportunities in protected natural areas. Two dimensions of scalability were particularly emphasized:

- **Political scaling**: Local projects can inspire policy shifts at regional and national levels. For instance, conflicts from high red deer densities arose in the surroundings of the SNP for decades (Blankenhorn et al. 1979). The sustained population growth could only be halted by two measures, which allowed stabilizing the population at a lower density (Haller 2002; Haller & Jenny, 2013): the introduction of small-scale hunting ban areas around the SNP and the implementation of special hunts following the short regular hunting season in September, both of which were supported by scientific research.
- **Methodological scaling**: Technological advances such as eDNA analysis (Leugger et al. 2025), remote sensing (Rossi & Wiesmann, 2024) or artificial intelligence for camera trap evaluation (Timcke 2025) extend research capacities to remote and inaccessible landscapes. These methods are minimally invasive, scalable, and particularly suitable for sensitive environments such as protected areas.

The scalability potential of local initiatives and methods has the capacity to extend beyond individual projects, enabling broader societal, ecological, and policy impacts. By integrating participatory approaches with innovative, minimally invasive technologies, such efforts can inform regional management strategies, enhance conservation outcomes, and serve as models for replication in other landscapes and jurisdictions.

Yet even with technological advances, ground truthing – direct field observations – remains indispensable for validating remote sensing data and ensuring robust interpretations. The SNP's 111-year research tradition constitutes an unparalleled resource in this context. Its long-term datasets allow researchers to track ecological and geomorphological processes over a century, offering insights into the interplay of climate, biodiversity, and land use (e.g., Schütz et al. 2003; Siegrist 2022; Gubler & Robinson 2025). Preserving and continuing these datasets is essential for future generations of landscape research.

Methodological diversity in landscape research

The diverse contributions underscored that understanding landscapes requires a comprehensive array of methodological approaches, combined with both inter- and transdisciplinary research frameworks. No single method suffices to capture the full complexity of landscapes; instead, a spectrum of approaches is required. A recently conducted project in Switzerland, ValPar.CH, on nature's values and services, provides a compelling example of how methodological diversity

can be translated into practice to generate a holistic understanding of landscapes. The ValPar.CH project addressed the *multiple values* of landscape and nature by combining ecological, social, economic, and planning perspectives. Ecological analyses included species distribution modeling, assessments of Nature's Contributions to People, environmental geodata, and remote sensing. Social perspectives were captured through surveys, transect walk interviews, geosemantic text analysis, and focus groups. Economic perspectives involved quantifying monetary values of Nature's Contributions to People. From a planning and management angle, scenarios were developed that linked natural processes, human-induced changes, and stakeholder visions. Complementary analyses included the development of archetypes of land systems and policy studies on governance structures. These strands were finally brought together in a co-production perspective that synthesized findings and translated them into recommendations for diverse stakeholder groups (Keller et al. 2025). Similarly, the symposium itself showcased the methodological richness of contemporary landscape research and served as a platform for co-producing knowledge, demonstrating how the integration of diverse tools and perspectives can yield more comprehensive and implementable insights (Figure 3).

Conclusion: research creates knowledge– landscape builds bridges

A consistent message across contributions was that landscapes are in flux (e.g., Wartmann et al. 2021). Physical processes and human activities continuously reshape landscapes, sometimes abruptly – such as through rockfall or landslides or through the construction of hydropower dams or other infrastructure – or gradually, as in glacier retreat or encroachment of pastures (e.g., Haller et al. 2013). Understanding these transformations requires integrating historical and contemporary perspectives. Long-term research provides critical insights into the drivers of change, whether climate dynamics, biodiversity decline, or land-use intensification. The symposium demonstrated that landscape is constantly evolving – geologically and ecologically – and so are the cultural and societal relations to landscapes. To understand and responsibly manage landscapes, research and long-term monitoring on landscape and its changes are indispensable since they document changes, enhance visibility, and deepen our understanding of how climate, biodiversity, and human actions interact over time. Long-term research is particularly vital for identifying landscape transformations in the global context. In this regard, the SNP's unique long-term datasets are a scientific treasure, shedding light on ecological change, hydrological cycles, geological dynamics, and socio-cultural transformations (Baur & Scheurer 2014).

Through its long-term collaboration with the Swiss Academy of Sciences, serving both as a network in the scientific community and as a bridge between science and policy, along with the other regional institutions, the research setting in the Lower Engadin and Val Müstair provides an exceptional platform for interdisciplinary research and exchange, as exemplified by the discussions and findings presented at the symposium.

As emphasized during the symposium, landscapes can function as bridges between disciplines – natural sciences, cultural studies, planning, and law – and between research and practice. But disciplines are not inherently capable of understanding each other, and translational work is necessary to facilitate meaningful dialogue. This is a key role of the Swiss Academies. Both the Research Commission of the SNP and the Forum Landscape, Alps, Parks aim at fostering this dialogue by providing network opportunities. The symposium both highlighted the challenges of comparing and understanding different viewpoints on landscapes while also emphasizing the potential of the landscape approach for interdisciplinary collaboration. While some of the research results presented at the Symposium are restricted to a local setting (the SNP and its surrounding area), the methods applied can inspire research in other areas too. In addition, debates about the plurality of landscapes values are an important topic for all Switzerland (e.g., Keller et al. 2025) and beyond.

In sum, the Research Symposium SNP+ reaffirmed that landscapes are dynamic, contested, and multidimensional. Research not only generates the knowledge needed to understand them but also fosters the societal and disciplinary bridges necessary for their sustainable future. After one intense day full of talks and discussions in Zernez and a visit of the special exhibition on the re-photographs in the exhibition centre of the SNP, discussions were continued on three excursions through the beautiful landscapes of the lower Engadin, the Val Müstair, and the SNP – locations that are widely appreciated for their cultural heritage, for their interplay between nature and culture, and for their wilderness.

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Authors

Stefanie Gubler[1]

is a mathematician and statistician who has a PhD in mountain permafrost modelling. She has worked as a climate scientist and is currently Head of the Research Commission of the Swiss National Park at the Swiss Academies of Sciences (SCNAT) in Bern, Switzerland.

Roger Keller[1]

is a geographer whose research focuses on the value and perception of nature and landscapes. He is a senior scientist at the University of Zurich and a project leader at the Swiss Forum Landscape, Alps, Parks (FoLAP).

Angelika Abderhalden[2]

is a landscape ecologist who specialises in aquatic ecosystems. She is the director of the Pro Terra Engiadina Foundation and the UNESCO Biosphere Reserve Engiadina Val Müstair in Scuol, Switzerland.

Linda M. Feichtinger[3]

is a biologist who holds a PhD in forest ecology from the Swiss Federal Institute for Forest, Snow and Landscape Research. She coordinates research and monitoring activities at the Regional Nature Park Biosfera Val Müstair in Tschierv, Switzerland.

Thomas Rempfler[4]

is a research associate in the Research and Monitoring Department of the Swiss National Park in Zernez, Switzerland. His work focuses on monitoring large mammals and their movement ecology.

Simon Aeschbacher[4]

is a population biologist with a PhD in evolutionary biology and a broad interest in research along the axis of genes, traits, and the environment. He is Head of the Research and Monitoring Department at the Swiss National Park, Zernez, Switzerland.

[1] Swiss Academy of Sciences, Bern, Switzerland

[2] UNESCO Biosfera Engiadina Val Müstair, Scuol, Switzerland

[3] Regional Nature Park Biosfera Val Müstair, Tschierv, Switzerland

[4] Swiss National Park, Zernez, Switzerland