

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

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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 Carpathians

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

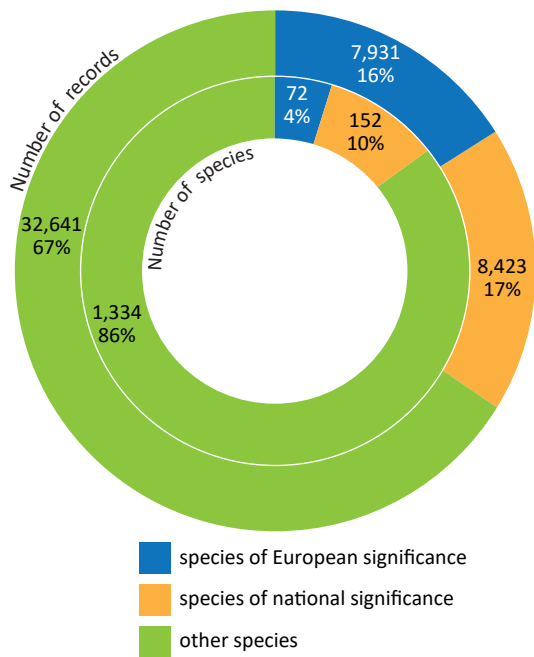


Figure 2 – Comparison of the total number of mapped plant and animal species and associated records in the CIMS for Malá Fatra National Park. The inner circle represents the distribution of species, while the outer circle illustrates the corresponding number of records.

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-

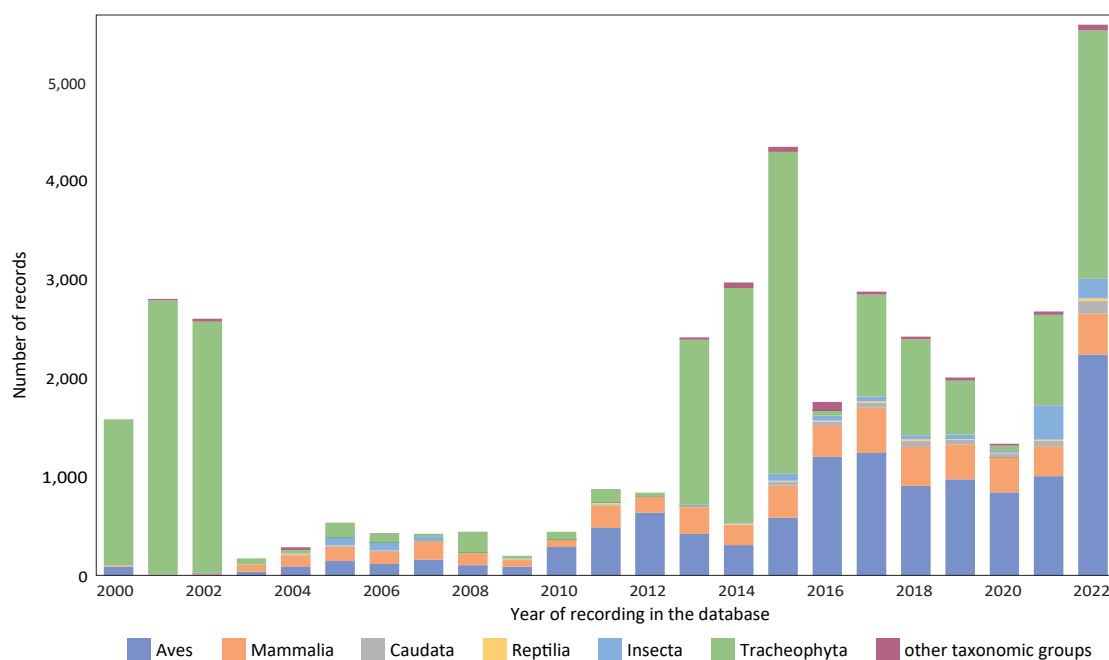


Figure 3 – Annual trends in recorded biodiversity data in the CIMS for Malá Fatra National Park, segmented by taxonomic groups (2000–2022; subsample size: $n = 39,975$ records). A subsample dataset was selected for better visualization and practical purposes, reflecting the volume of data collected over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

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

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

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-

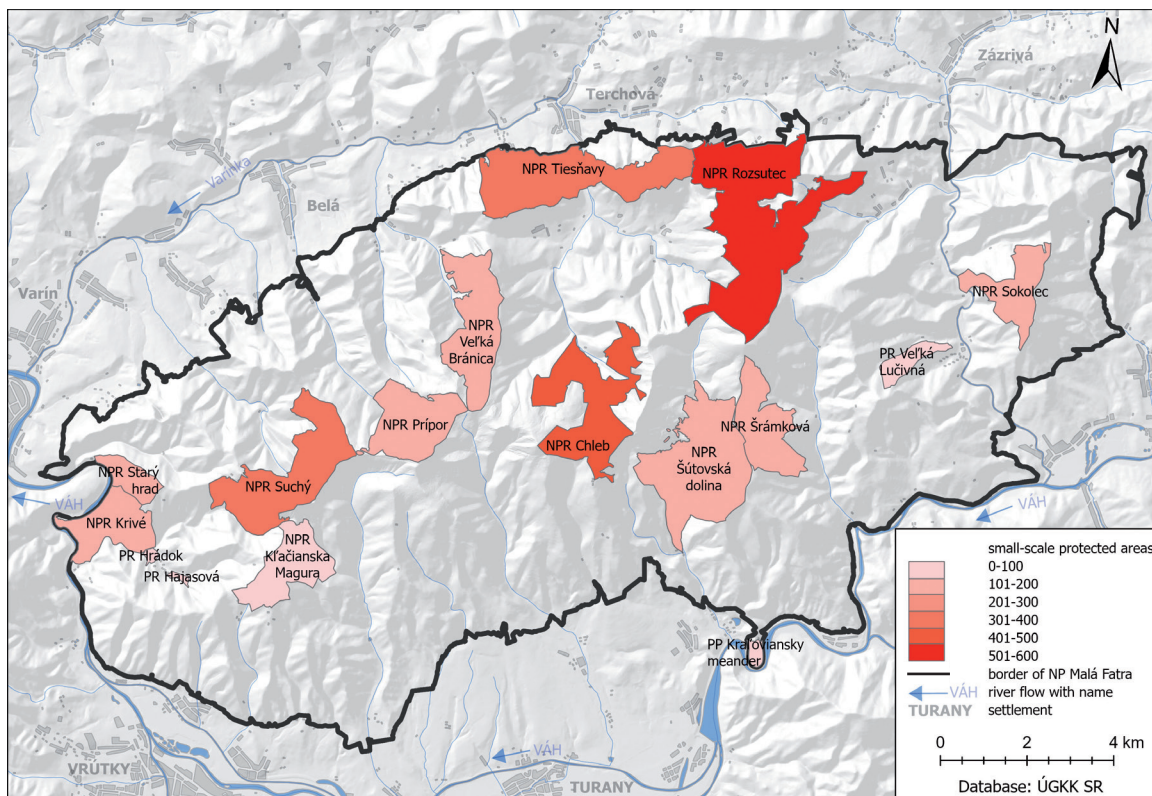


Figure 4 – Number of species mapped within small-scale protected areas of Malá Fatra National Park (NPR – national nature reserve, PR – nature reserve).

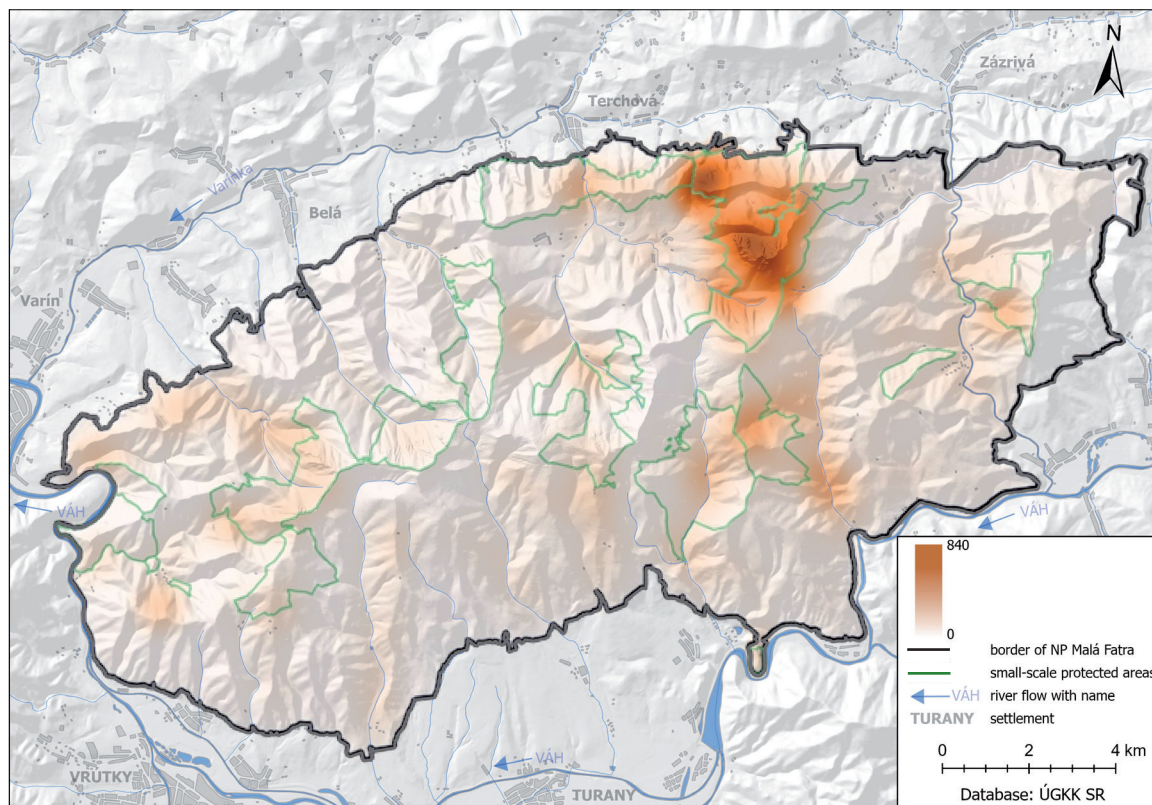


Figure 5 – Heat map depicting zoological biodiversity monitoring hotspots in Malá Fatra National Park, highlighting areas of concentrated survey efforts.

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.

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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
	Jungermannopsida	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