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Mountains are recognised not only as ecological treasures but also as living laboratories where the interplay of biodiversity, climate dynamics, and human culture converge. In this issue of eco.mont, we present a range of articles that exemplify the geographic diversity, thematic depth, and interdisciplinary scope of contemporary mountain research, from the Baekdudaegan range of Korea to the highlands of Austria, Switzerland, and China.

Research frontiers in Asia's mountain ecosystems

The article on the Baekdudaegan Mountains Reserve offers a bibliometric and topic modelling analysis of scientific literature on the Baekdudaegan Mountains – a 1,400 km-long protected mountain range that is central to the ecological and cultural identity of the Korean peninsula. Using bibliometric analysis and the Latent Dirichlet Allocation (LDA) method, the authors identify six dominant research clusters: biochemical pathways, forest dynamics, genomic taxonomy, seedling ecology, biodiversity conservation, and climate change. This integrative approach not only highlights the growing scientific attention to the region – particularly since 2017 – but also serves as a valuable resource for guiding future conservation policy and interdisciplinary research.

Similarly, a case study from the Daqi Mountain Provincial Nature Reserve in central China draws attention to the fragile balance of highland forest ecosystems. The reserve is home to several endangered species that now face existential threats from global warming, biological invasions and human disturbance. The article calls for improved fire management strategies and a broader framework for biodiversity monitoring, and highlights the urgent need for coordinated conservation efforts.

Protected areas in Europe: glacial legacies and wilderness narratives

Turning to the European Alps, we visit the Hohe Tauern National Park (HTNP), Austria's oldest and largest national park, which has a long tradition of glaciological research dating back to 1879. The study details the development of glacier monitoring and discusses the educational and ecological importance of the park's glaciers. As glacier retreat accelerates, HTNP is becoming an important site not only for scientific study, but also for environmental education and advocacy.

Switzerland's oldest national park, the Swiss National Park (SNP), offers a different but equally compelling story. Founded in 1914 as a rewilding experiment, the SNP has long struggled to communicate the meaning and value of wilderness to the public. An insightful article in this issue chronicles the development of a major new permanent exhibition at the National Park Centre in Zernez, which opened in 2023. The exhibition represents years of planning and public engagement, translating complex ecological issues into a tangible and engaging visitor experience.

Global networks and local action

Finally, we feature an update on the World Network of Mountain Biosphere Reserves (WNMBR), established in 2021 under the auspices of UNESCO's Man and the Biosphere programme. Comprising over 80 mountain biosphere reserves, the WNMBR aims to foster collaboration and innovation across mountain regions. Through knowledge exchange, joint research, and inclusive governance, the network underscores the necessity of global cooperation in addressing the challenges of sustainable development in mountainous areas.

Together, these contributions reflect the growing complexity and global scope of mountain research. Whether through technological innovation, conservation strategy, or public education, the work featured highlights the critical importance of mountains as sentinels of environmental change and custodians of cultural and biological heritage. We hope this issue inspires further interdisciplinary exploration and action across mountain landscapes worldwide.

Valerie Braun
co-editor
June 2025

Unveiling research on Baekdudaegan: bibliometric analysis and Latent Dirichlet Allocation topic modelling approaches

Thakur Dhakal, Tae-Su Kim, Shraddha Tiwari, Seong-Hyeon Kim, Anteneh Bongasie, JunYoung Kim, Su-Jin Kim & Gab-Sue Jang

Keywords: Baekdudaegan, biodiversity, Latent Dirichlet Allocation, sustainable development goals, text mining

Abstract

Baekdudaegan is a protected mountain range that spans 1,400 km across the Korean Peninsula and serves as a hub of biodiversity and cultural heritage. This study presents a comprehensive analysis of research insights into this complex mountain ecosystem through bibliometric analysis and Latent Dirichlet Allocation (LDA) topic modelling approaches using metadata from 165 scholarly publications sourced from the Web of Science (WoS) core collection. We observed a discernible upward trend in Baekdudaegan-related literature, with a notable surge in scholarly interest post-2017, primarily from institutions such as the Baekdudaegan National Arboretum and the Korea National Arboretum. According to WoS categories, the examined research was dominated by plant science, ecology and environmental science clusters. Employing the LDA model to the corpus of texts extracted from keywords and abstracts of each observed literature, we identified six principal research topics: biochemical pathways, forest ecosystem dynamics, genomic taxonomy, seedling dynamics, biodiversity conservation and climate change. Finally, we visualized the keyword network and LDA-trained word cloud topics. The findings of this study enhance a deeper understanding of Baekdudaegan Mountains research, offering valuable insights for researchers and policymakers. This study serves as a resource for future investigations and informed decision-making regarding the sustainable management of mountain ecosystems.

Profile

Protected area

Baekdudaegan

Mountains Reserve

Mountain range

Baekdudaegan

mountain range

Country

North and South Korea

Introduction

Mountains serve as significant reservoirs of biodiversity, regulate climate and provide vital resources such as freshwater fuel and other natural materials essential for human survival and ecological balance (Körner 2004; Payne et al. 2017). Research on mountains is increasing and essential for understanding their conservation challenges, ecological dynamics and the impacts of climate change, as well as to provide the status of mountain studies globally (Gunya & Sarmiento 2022; Solár & Solár 2020; Thaler et al. 2021). Much research has been conducted in various disciplines within a variety of approaches and frameworks (Kratzer 2018; Palau & Claramunt-López 2024). Strengthening mountain specific research is necessary to assess sensitivity to global climate scenarios and to ensure sustainable mountain ecosystems (Negi et al. 2014; Schmidt-Vogt et al. 2016). Recent studies have highlighted the importance of expanding literatures, particularly those relating to protected mountain ranges such as Baekdudaegan in East Asia (Chung et al. 2017; Schroth et al. 2009; Theobald et al. 2024).

The Baekdudaegan mountain range (BMR) has significant historical, ecological, cultural and conservation importance in the Korean Peninsula (Choi 2004; Chung et al. 2018a). It is also called the *spine of Korea*, stretching more than 1,400 km across the Korean Pen-

insula, from the northern border with North Korea to the southernmost point of South Korea (Cho & Chun 2015; Min et al. 2019). Baekdudaegan's classification as a biosphere reserve and other conservation efforts have been implemented by governmental and non-governmental organizations (Park & Lee 2014; Hayes 2010). Significant obstacles still exist in some regions despite these initiatives, such as conflicting land use interests, economic constraints and political difficulties (Lee 2019). Previous studies have explored comprehensive strategies to tackle these issues including community involvement and sustainable development methods; strong legislative frameworks are necessary for successful conservation (Cárdenas et al. 2018; Cho et al. 2022; Kim 2011). Scholars have directed their focus towards understanding the significance and characteristics of notable mountains like those of Baekdudaegan in Korea, resulting in a burgeoning of literature offering diverse perspectives (Altaweel et al. 2019; Arroyave et al. 2024).

When one explores the latent structures of existing research, bibliometric studies and topic modelling emerge as effective tools for communicating with scholars (Calvo et al. 2022; Cheng et al. 2018; Davies et al. 2012). Bibliometric studies shed light on research development and its significance by analysing literature quantitatively and focusing on publication patterns and research themes (Cobo et al. 2011; Donthu

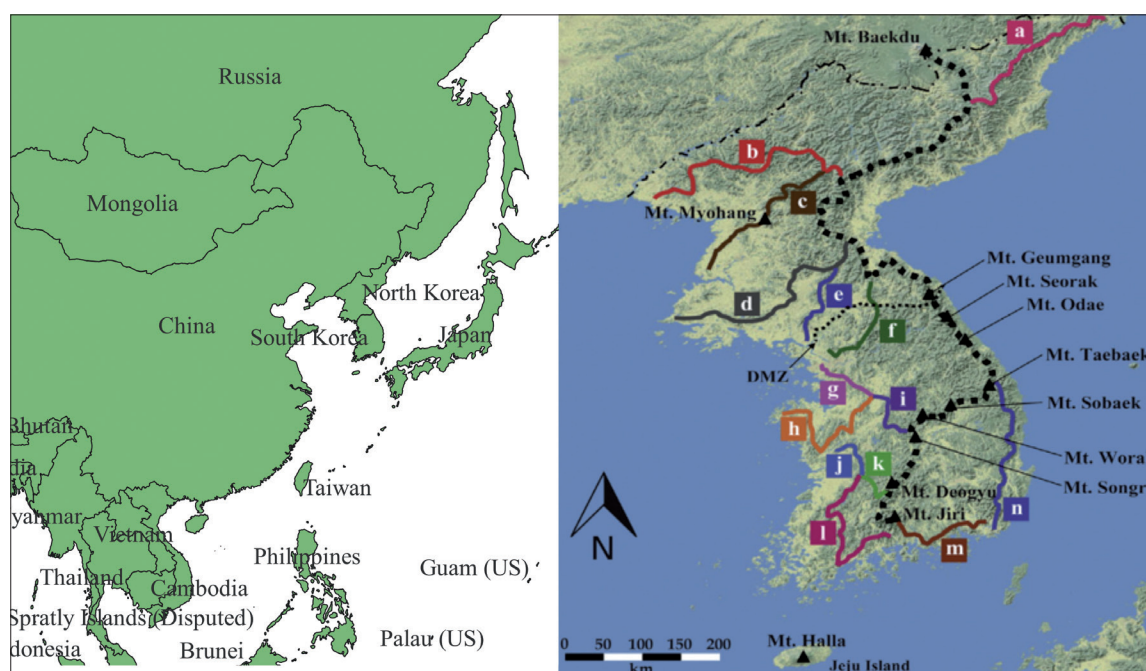


Figure 1 – Location of Korea in the East Asian map and the Baekdudaegan mountain system (where the main ridgeline is represented by a thick black dashed line), which runs north to south along the Korean Peninsula. The thin curved lines in diverse colours represent 14 subsidiary mountain ranges of the Baekdudaegan Mountains (which form one jeonggan and 13 jeongmaeks): a – Jangbaekjeonggan; b – Cheongbukjeongmaek; c – Cheongnamjeongmaek; d – Haeseojeongmaek; e – Imjinbukyesungnamjeongmaek; f – Hanbukjeongmaek; g – Hannamjeongmaek; h – Geumbukjeongmaek; i – Hannamgeumbukjeongmaek; j – Geumnamjeongmaek; k – Geumnambonamjeongmaek; l – Honamjeongmaek; m – Naknamjeongmaek; and n – Nakdongjeongmaek (Chung et al. 2017). Dotted line: DMZ – Korean Demilitarized Zone.

et al. 2021; Gaviria-Marin et al. 2018; Kratzer 2018). Understanding content from a large corpus of documents may be facilitated by means of topic modelling, which uncovers the latent thematic patterns of words (Abdelrazek et al. 2023; Daud et al. 2010). In recent decades, bibliometric and natural language topic modelling techniques have garnered increasing research interest and are gaining in popularity on account of the development of new software programs, the ability to handle large databases and sophisticated machine learning techniques (Ellegaard & Wallin 2015; Grisales et al. 2023; Wang et al. 2023).

A combination of probabilistic natural language-based topic modelling and qualitative bibliometric research methods helps delve into the significance, research trajectories and prospective avenues of scholarly inquiry (Cobelli & Blasi 2024; Jiang et al. 2016). These studies have been conducted in multiple sectors, including ecological dynamics, cultural heritage prevention, climate change, energy conservation and socioeconomic studies (Vlase & Lähdesmäki 2023; Woolston 2023). During our literature search, comprehensive studies on mountain research using bibliometric analysis and topic modelling were limited. Therefore, this paper aims to fill this gap by conducting an in-depth analysis through bibliometrics and topic modelling to analyse research relating to the BMR, offering valuable insights for international dialogues concerning mountain conservation and ecosys-

tem management. The findings and approach enhance understanding and advance knowledge in the field of mountain research.

Materials and methods

Baekdudaegan

Baekdudaegan, designated as the Baekdudaegan Mountains Reserve is located in East Asia and is the ecological axis of the Korean Peninsula. The BMR is critical to Korea's natural heritage and the global significance of its biodiversity. It is an approximately 1,400 km-long central mountain range that extends from Mt Baekdu, North Korea to Mt Jiri, South Korea (Figure 1). There are fourteen subsidiary mountain ranges connected to the BMR (one jeonggan and 13 jeongmaeks), see Figure 1. Baekdudaegan is a treasured representation of Korean identity considering its varied ecosystems, immaculate scenery and rich cultural legacy. It is a key corridor for wildlife, a place of inspiration for artists and a path for spiritual seekers. Baekdudaegan plays a vital role in the country's climate and water systems. It symbolizes Korea's natural heritage and is a focal point for conservation initiatives (Je-Hun & Doo-Hee 2013; Jung 2015; Kim et al. 2023).

The present conservation status of the BMR presents considerable differences between South and North Korea. In South Korea, the Korea Forest Service passed the Baekdudaegan Protection Act in 2003

and designated the Baekdudaegan protected area in 2005 (Cho & Chun 2015). South Korea offers a good degree of protection, as large parts are covered by the network of protected areas (Chung et al. 2017). In contrast, the North Korean part of the Baekdudaegan mountains system is rarely covered by protected areas, whereas deforestation affects large parts, including in the globally recognized Mt Baekdu Biosphere Reserve zone (Tang et al. 2010). The mountain range is rich in species diversity, with an estimated 4,662 vascular plants, 135 bird, 36 mammals and 32 amphibian and reptile species (Chung et al. 2018a). In the South Korean section, there are 379 villages linking directly to BMR (Kim et al. 2023). In this study, we have explored the latent themes contents of research centred on the glacial refugium of the BMR.

Data

Scholarly data can be obtained from various platforms, including Web of Science (WoS), Scopus, Google Scholar, Semantic Scholar, PubMed and Crossref. WoS is a comprehensive science-indexed database that extensively collects academic journals, conference proceedings and the most accepted peer-reviewed scholarly publications (Falagas et al. 2008; Li et al. 2018). Considering the relevance and impact of publications, this study has examined Baekdudaegan-related research sourced from the WoS Core Collection. A total of 165 scholarly publications retrieved using the search function {ALL="Baekdudaegan"} in the WoS Core Collection, as of 27 December 2023, have been examined for bibliometric analysis and topic modelling in this study (see Supplementary File S1). To examine the transition of dominant latent words and modelled topics, keywords and abstracts of the literature were used without considering general words such as auxiliary verbs, connecting words, stop words and punctuation after transferring all text into lowercase. The research data for 2023 were incomplete. Therefore, we analysed the publication trend and assessed the goodness of fit with R² value (Cameron & Windmeijer 1997), along with overall citations, based on the literature data between 2004 and 2022.

Bibliometrics insights

Bibliometrics offer valuable insights into scholarly communication dynamics and the impact of research across academic disciplines (Ninkov et al. 2022; Pan et al. 2024). Reporting influential articles is essential for recognizing impactful research domains, the sustainable development goals (SDG) alignment of articles enhances the strategic value of academic efforts and WoS categories can effectively navigate and make use of the specific field of scholarly literature. The contributing institution facilitates the potential stakeholders in the research ecosystem, and keywords and their networks enhance an understanding of how different concepts are interconnected (Calvo et al. 2022; Cheng et al. 2018; Davies et al. 2012). Similarly, the number

of authors contributing to a single publication attests to collaborative projects and the authors' network suggests an association between two or more scientists pursuing shared goals (Kratzer 2018; Ortega 2014; Venturini et al. 2024).

We therefore examined the influencing research, SDG alignments, WoS categories, collaborative institutions and authors using the WoS core collection analysis tool. The relationship among keywords that contained at least two publications were visualized using a co-occurrence network graph that was generated using VOS Viewer software version 11.6.18 (Van Eck & Waltman 2018). The keywords and authors networks were graphed with the default configuration of the VOSviewer software (Van Eck & Waltman 2018). The ten most cited articles were summarized with key findings and annual citation rate. We visualized the annual latent words, which examined a collection of five dominant words for each year, and the transitions of the most frequently used 30 words were presented in the RStudio environment (R Core Team 2023).

Topic modelling

Topic modelling is an unsupervised probabilistic text classification technique used to uncover latent textual data frameworks (Griffiths & Steyvers 2004). With advances in research and development (R&D) and robust computational tools, various techniques such as Latent Dirichlet Allocation (LDA) (Blei et al. 2003), non-negative matrix factorization (Da Kuang et al. 2015), correlation (Blei & Lafferty 2005), joint sentiment (Lin & He 2009), bidirectional encoder representations from transformers (Devlin et al. 2019) and models in natural language processing (NLP) have been applied to topic modelling (Abdelrazek et al. 2023). Several researchers have gravitated to LDA, which has been successfully applied to different research clusters (Du et al. 2021; Jelodar et al. 2019; Laureate et al. 2023; Vayansky & Kumar 2020). LDA is highly recommended for analysing latent topics because of its advantages in flexibility and coherence (Stevens et al. 2012; Vayansky & Kumar 2020). LDA is a generative probabilistic model that follows the three-level hierarchical Bayesian rule (Blei et al. 2003).

LDA characterizes documents as distributions over topics, with each topic represented as a collection of words, thereby revealing topic generation within a corpus (Vayansky & Kumar 2020). Using a Dirichlet distribution, LDA initially samples a document-specific multinomial distribution over subjects to construct a document. Words from these topics were sampled repeatedly based on the Bayesian rule (Blei et al. 2003). In LDA, α and β are the corpus-level hyperparameters and are assumed to be sampled once while generating a corpus; θ is the document-level parameter sampled once in a document; and Φ is the topic-level distribution of words. The variables z and w are word-level variables sampled once for each word in each document, as graphically represented in Figure 2. In LDA,

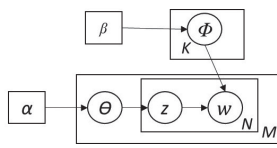


Figure 2 – A graphical representation of the latent Dirichlet allocation (LDA) model. The Figure illustrates the relation between documents, topics and words. The letters α and β are the corpus-level hyperparameters; θ is the document-level parameter sampled once in a document; Φ is the topic-level distribution of words; z and w are word-level variables sampled once for each word in each document; M is the total number of documents; N is the number of words in each document; and K is the predefined number of topics (Blei et al. 2003).

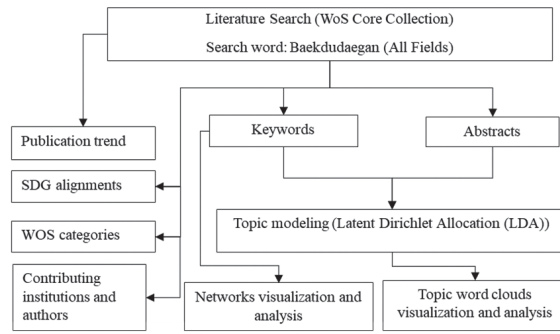


Figure 3 – Workflow summary for bibliometric and topic modelling analysis of Baekdudaegan research indexed in WoS database from 2004 to 2022.

each M document is a mixture of K latent topics and each topic describes a multinomial distribution of N words (Blei et al. 2003). These parameters have been estimated using Gibbs sampling and variational expectation maximization (VEM) approaches, implemented via the *topicmodels* package within the RStudio environment (Grün & Hornik 2011). Gibbs sampling is more accurate and provides more stable topics than the VEM approach (Marani & Baumer 2023; Mardones-Segovia et al. 2022; Zubir et al. 2018). Leveraging this established understanding, the current study employed the Gibbs sampling method for its topic modelling.

It is essential to determine the appropriate number of topics in topic modelling (Arun et al. 2010; Cao et al. 2009). In this study, the possible number of optimal topics (K) was determined by comparing four metrics – Griffiths 2004 (Griffiths & Steyvers 2004), Cao 2009 (Cao et al. 2009), Arun 2010 (Arun et al. 2010) and Deveaud 2014 (Deveaud et al. 2014) – each

offering distinct perspectives on topic selection. Griffiths 2004 assesses topic coherence by measuring the semantic similarity among the top words within each topic, while Cao 2009 focuses on model perplexity, indicating the model's ability to predict unseen data. Arun 2010 strikes a balance between model complexity and coherence by maximizing intra-topic coherence and minimizing inter-topic separation. Deveaud 2014 provides a comprehensive evaluation of topic model quality, considering both coherence and coverage. Our study evaluated these metrics by employing a range of optimization techniques: Griffiths 2004 and Deveaud 2014 were optimized for maximization, while Cao 2009 and Arun 2010 were optimized for minimization. The topic $K=10$ was initially arbitrarily defined, and the scenarios were evaluated for each metric using the *ldatuning* package (Murzintcev & Chaney 2022). Visualizing a larger number of words can lead to overcrowding in the word cloud, making it difficult

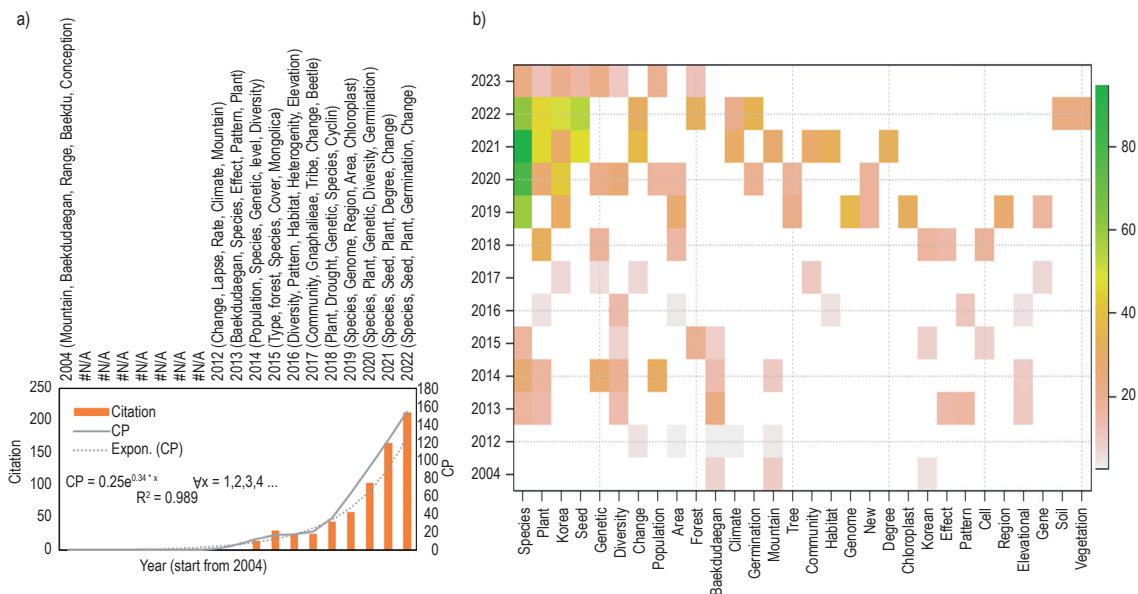


Figure 4 – WoS-indexed Baekdudaegan research contents: a) cumulative publication (CP), citation trend and exponential fit of CP (dominated words in each year in parentheses; #N/A: no record), b) highly dominated 30 words transitions over time (colourbar represents the frequency of words).

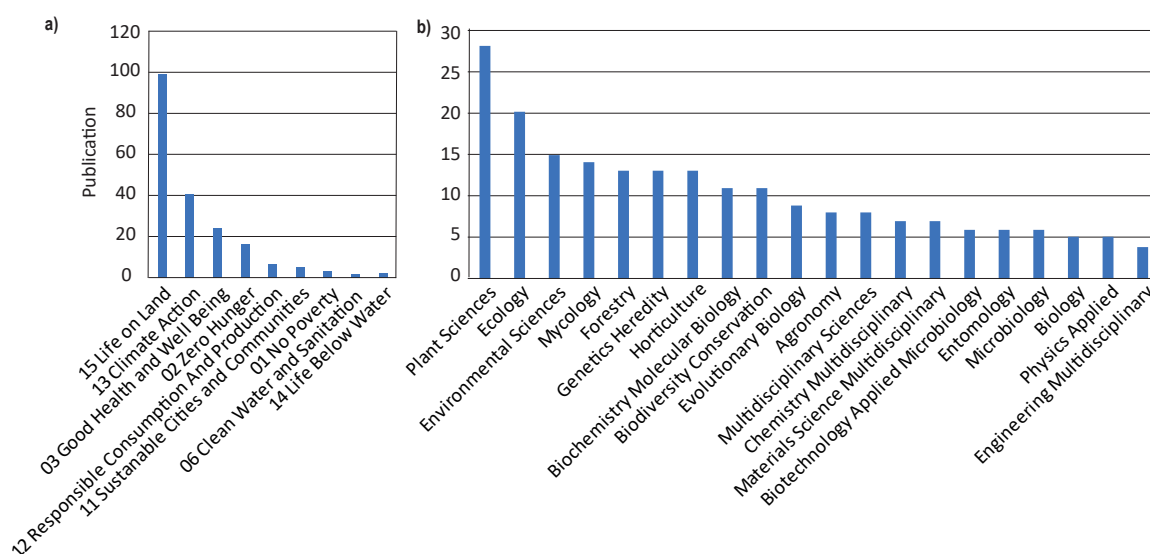


Figure 5 – Frequency plots for research alignment to a) Sustainable Development Goals and b) top 20 Web of Sciences categories.

for viewers to interpret. We therefore extracted the first 100 dominant words for each topic and visualized the word cloud computed in the RStudio environment (Fellows 2022; R Core Team 2023). A detailed summary of research flow is shown in Figure 3.

Results

Publication trend

Choi (2004) was the first report of the 165 publications (Articles: 157; Reviews: 4; Proceeding papers: 1; Editorial material: 2; Meeting abstracts: 1) publications indexed in the WoS database. Remarkably, there was a conspicuous absence of WoS-indexed publications from 2004 to 2012, followed by a notable surge in publications post-2017 (Figure 4a). There is an upward trajectory in cumulative publications, characterized by an exponential growth rate of 0.34 literatures per year with a constant multiplier of 0.25 ($R^2 = 0.989$). Concurrently, citations exhibit a corresponding increase correlating with the rising rate at 5.19 citations per publication. When scoping the influence publication on the topic *Baekdudaegan*, *Altitudinal patterns of plant species richness on the Baekdudaegan Mountains, South Korea: mid-domain effect, area, climate, and Rapoport's rule* (Lee et al. 2013) was observed as the most cited (41 times and 3.42 citations per year) (Table 1). The existing literature on Baekdudaegan mainly focuses on species distribution, climate influences and the glacial refugium characteristics of this mountain region (Chung et al. 2017). The latent words derived from keywords assigned by authors and the abstracts of publications revealed a notable shift in research focus over time. Initially, the discourse was dominated by terms such as *Baekdudaegan* and *mountain*, gradually transitioning to include words like *species*, *seed*, *plant* and *germination* in recent years (as indicated by x-level in parentheses in Figure 4a). Further scrutiny concentrated on the five most frequently employed words, leading to the ex-

traction of the thirty most recurrent terms over time. Notably, terms such as *species*, *plant* and *seed* emerged as dominant themes across various temporal segments, as depicted in the heatmap illustrated in Figure 4b.

We revealed that the research outputs were predominantly aligned with nine specific SDGs that were observed using the SDGs feature within the WoS core collection analysis tool. Notably, a substantial portion of the research corpus (comprising 99 articles) was aligned with the exploration of SDG 15, concerning life on land. This was closely followed by contributions to SDG 13, addressing climate action, and SDG 3, focusing on good health and well-being (Figure 5a). The examined literature ranged from various (a total of 45) WoS categories, with plant science as the dominant WoS category, followed by ecology, environmental science and forestry (see top 20 categories in Figure 5b).

We examined the authors' affiliations, number of authors per article and dominant authors' publications (Figure 6) to identify collaborating institutes and authors. A total of 454 authors from 171 institutions contributed to the examined literature. The Baekdudaegan National Arboretum was the dominant organization, followed by the Korea National Arboretum, Chonnam National University and Korea Forest Research Institute (Figure 6a). Similarly, there were 38 publications contributed by five authors, with the maximum number of authors per article being 17 and an average of eight authors (Figure 6b). The author Kim, YS made the highest number of occurrences ($n=25$), followed by Na, CS ($n=19$) and Kim, DW ($n=18$) (Figure 6c).

Keyword and authors' networks

A total of 399 co-occurring keywords were identified while analysing the VOSviewer framework, where 65 words met the threshold of the minimum number of occurrences (two times) of a keyword visualized in the network graph with thematic clusters (Figure 7a).

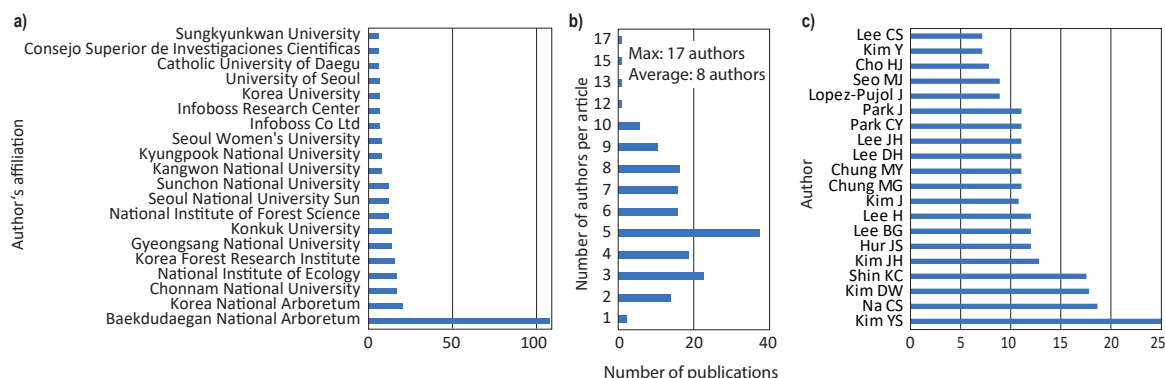


Figure 6 – Publication frequency of a) top 20 dominated institutions b) number of authors per article and c) top 20 authors.

It was observed that the keyword *conservation* was positioned as the central theme of networks linked to the terms *genetic diversity*, *biodiversity*, *diversity*, *phylogeography*, *biosphere reserve* and *Baekdudaegan*. These keywords focus on environmental and ecological research, with a specific emphasis on areas such as the Baekdudaegan Mountains, biodiversity and evolutionary genetics. Similarly, we graphed the co-authorship network (Figure 7b) to visualize the collaborative community, especially working on conservation and biodiversity topics related to the themes linked to the Korean Baekdudaegan environment. We observed that Kim, Yeong-su (Kim Y.S.), Kim, Dae Wook (Kim D.W.), Kim, Jeong Yoon (Kim J.Y.) and Woo H.S. were serving as central nodes and they connected with other authors, forming a collaborative research group. Other researchers such as Kim Jae Woo (Kim J.W.) and Lee, Andosung (Lee A.S.) led to smaller clusters within the network.

Topic visualization

We observed extreme values of the four metrics, Griffiths 2004, Cao 2009, Arun 2010 and Deveau 2014 on the LDA model (Figure 8). Arun 2010 and Griffiths 2004 demonstrated a better fit when increasing the number of topics (K). Good convergence was observed in Cao 2009 and Deveau 2014 at $K=6$ that we proceed in LDA modelling for further analysis.

The thematic delineations were examined to facilitate a deeper understanding of the multifaceted dimensions of research within the examined literature. We found six distinct topics, each characterized by dominant terms encapsulating key thematic elements. Word clouds depicting the top 100 dominant words for each topic were visualized (Figure 9). The first topic exhibited a prevalence of terms such as *activity*, *plant*, *cell*, *enzyme* and *production*, indicative of a focus on biochemical processes and productivity within plant systems. In the second topic, prominent terms

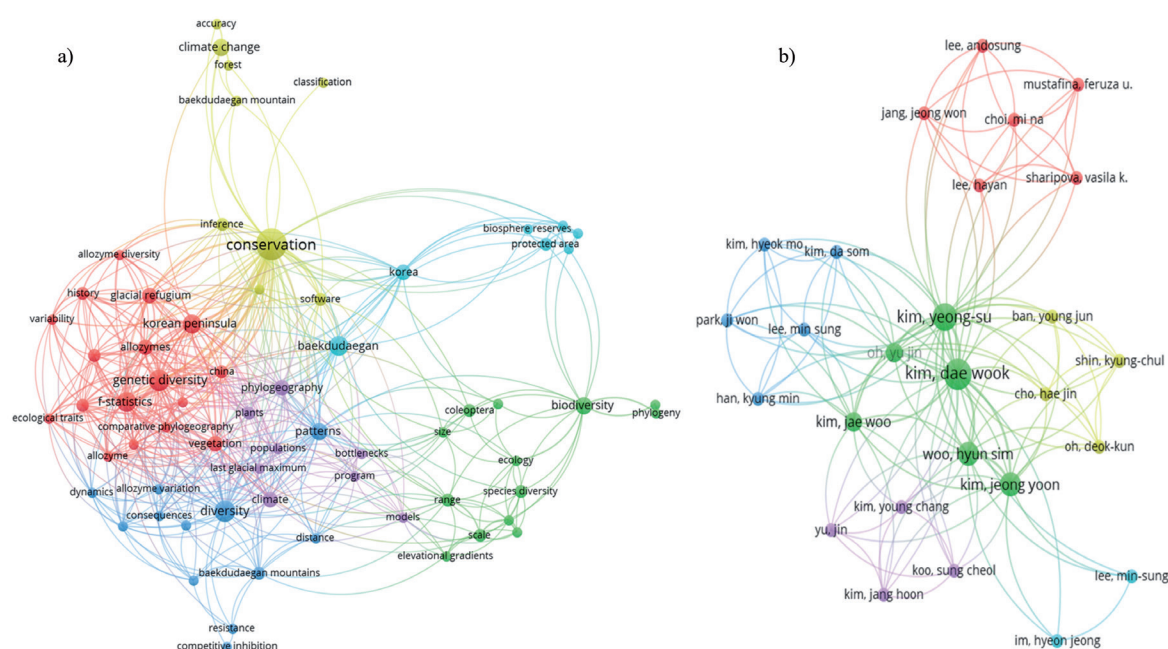


Figure 7 – Network visualization of (a) co-occurrence of keywords and (b) co-authorship relationships (node colors represent thematic groups, where node size corresponds to the frequency of occurrence (for keywords) or the number of publications (for authors) and link thickness shows the strength of associations, based on co-occurrence frequency).

included *forest*, *species*, *vegetation*, *area* and *soil*, suggesting an emphasis on ecosystem dynamics and landscape-level interactions within forested environments. The third topic was characterized by terms such as *species*, *genome*, *region*, *gene* and *taxon*, suggesting a concentration on the genomic and taxonomic aspects of biodiversity. Conversely, the fourth topic featured terms like *seed*, *germination*, *temperature*, *treatment* and *dormancy*, indicating a focus on the dynamics and mechanisms governing seed behaviour under varying environmental conditions. The fifth topic highlighted terms such as *genetic*, *population*, *species*, *Baekdudaegan* and *diversity*, suggesting a thematic exploration of genetic diversity and population dynamics, particularly within mountainous regions. Lastly, the sixth topic was marked by words such as *species*, *change*, *plant*, *climate* and *pattern*, indicating an investigation into the impacts of climate change on plant communities and ecological patterns. Through careful examination of the word distribution within each topic, we synthesized the overarching themes into six categories: bioactive plant components, forest ecosystem restoration, genomic diversity, seed germination dynamics, mountain biodiversity and climate-induced changes.

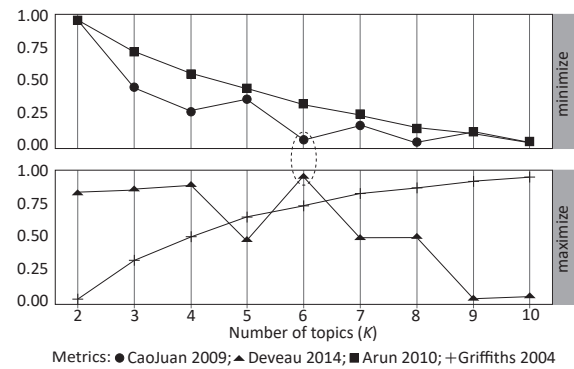


Figure 8 – Estimation of the optimal number of topics (six topics) based on LDA model quality using four measures: Griffiths (2004), CaoJuan (2009), Arun (2010), and Deveau (2014). The top panel shows metrics (CaoJuan (2009) and Arun (2010)) that should be minimized, as lower values indicate better topic separation. The bottom panel presents metrics (Griffiths (2004) and Deveau (2014)) that should be maximized, as higher values reflect improved topic coherence and model performance. Based on these measures, six topics were selected as the optimal number.

Table 1 – Top ten most-cited research and their findings linking to Baekdudaegan indexed in WoS until 27 December 2023. TC: Total citations; C/Y: Citations per year

Title (Type)	Key findings	TC (C/Y)
Altitudinal Patterns of Plant Species Richness in the Baekdudaegan Mountains, South Korea: Mid-domain Effect, Area, Climate and Rapoport's rule (Article) (Lee et al. 2013)	Hump-shaped species richness pattern in the Baekdudaegan mountains where plant richness is influenced by mid-domain effect (MDE) and climatic factors.	41 (3.42)
The role of the Baekdudaegan (Korean Peninsula) as a major glacial refugium for plant species: A priority for conservation. (Review) (Chung et al. 2017).	The Baekdudaegan mountains hypothetically served as a glacial refugium and have genetic diversity of plant populations. They are also regarded as the holy mountain system of Korea.	40 (5)
Environmental drivers of patterns of plant diversity along a wide environmental gradient in Korean temperate forests. (Article) (Lee & Chun 2016).	Plant species distribution in the Baekdudaegan mountains follows diverse elevational patterns, with regional area, habitat heterogeneity and climate being significant influencing factors.	26 (2.89)
Incorporating differences between genetic diversity of trees and herbaceous plants in conservation strategies. (Article) (Chung et al. 2020)	Along the Baekdudaegan mountain network, forest trees exhibit higher genetic diversity at both population and species levels compared to annuals and herbaceous perennials and herbaceous plant populations are low and vulnerable to the loss of genetic diversity.	23 (4.6)
The Korean Baekdudaegan mountains: A glacial refugium and a biodiversity hotspot that needs to be conserved. (Article) (Chung et al. 2018a).	The Baekdudaegan, a biodiversity hotspot with cultural and spiritual significance, requires concerted conservation and cooperation efforts for its sustainable management.	23 (3.29)
Large effective population sizes and high levels of gene flow between subpopulations of <i>Lilium cernuum</i> (Liliaceae). (Article) (Chung & Chung 2014).	In the Baekdudaegan mountain region, there are high levels of within-population genetic variation and low between-population genetic differentiation. Cold-adapted species are found in large refugial areas.	16 (1.45)
Were the main mountain ranges in the Korean Peninsula a glacial refugium for plants? Insights from the congeneric pair <i>Lilium cernuum</i> – <i>Lilium amabile</i> . (Article) (Chung et al. 2014).	The Baekdudaegan mountain range serves as glacial refugia for boreal plant species, providing stable habitats and supporting large population sizes.	15 (1.36)
Potential distribution of amphibians with different habitat characteristics in response to climate change in South Korea. (Article) (H.W. Kim et al. 2021)	Amphibian species face heightened vulnerability to climate change, anticipating significant declines and potential extinctions. Their habitats are projected to concentrate along the Baekdudaegan mountain range and in the southeastern region, demanding urgent conservation action.	14 (3.5)
Comparison of genetic variation between northern and southern populations of <i>Lilium cernuum</i> (Liliaceae): Implications for Pleistocene refugia. (Article) (Chung et al. 2018b).	There is genetic diversity of boreal or temperate plant species in the southern glacial refugium in the Baekdudaegan mountains and in the northern area (Northeast China and the Russian Far East).	14 (2)
Driven to the edge: Species distribution modeling of a clawed salamander (Hynobiidae: <i>Onychodactylus koreanus</i>) predicts range shifts and drastic decrease of suitable habitats in response to climate change. (Article) (Y. Shin et al. 2021)	Climate change significantly impacts amphibian diversity, resulting in a northeastward shift of their habitat suitability towards high-elevation areas along the central ridge of the Baekdudaegan range, as it serves as a climatic refugium for the species.	12 (3)

Overall, research linked to the BMR is an increasing trend, largely due to its critical role in conservation and ecosystem management. The research is predominantly aligned with SDG 15, particularly in the field of plant science, and is largely conducted by the Baekdudaegan National Arboretum. The unsupervised topics extracted from the LDA model also revealed a strong emphasis on conservation, biodiversity and ecosystem services. Given the growing importance of the BMR and similar protected mountain areas, it is crucial to continue research and systematically to monitor their conservation status.

Discussion

Mountains are special places to be protected for sustainable conservation (Kollmair et al. 2005). They serve as habitats for species worldwide, emphasizing the importance of effective management strategies and monitoring such indicators as conservation status, threats, socioeconomic context and social valuation and perception (Chung et al. 2017; Schmeller et al. 2022; Shin 2004). Representing approximately a quarter of the world's land area across 139 countries, mountains are integral landscapes of the planet, necessitating research to understand their systems and current threats (Kohler et al. 2012; Ng 2022; Schmeller et al. 2022). The inclusion of a dedicated mountain chapter in UN Agenda 21 (United Nations 1992, Chapter 13: Managing Fragile Ecosystems: Sustainable Mountain Development) catalysed significant progress in mountain research, leading to the establishment of global mountain institutions such as the Global Moun-

tain Biodiversity Assessment Network, the Mountain Research Initiative, the International Centre for Integrated Mountain Development and the Mountain Partnership (Bhandary 2015; Grumbine & Xu 2021; Price et al. 2021). These institutions facilitate interdisciplinary research, knowledge exchange with local communities and awareness-raising efforts regarding mountain ecosystems and their services at both local and global levels. As global and local interest in mountain research continues to rise, literature centred on mountainous regions has experienced a notable surge (Gurgiser et al. 2022; Ng 2022). Research linked to local mountains highlights indigenous conservation practices, traditional ecological knowledge and community-based management strategies that support sustainable conservation efforts (Farina & Mullet 2024; Garrard 2012; Palau & Claramunt-López 2024; Xu et al. 2023). Acknowledging the assistance of bibliometric studies and LDA modelling to identify major research concerns and guide future investigations, the current study examined the insights from 165 research papers linked to the Korean BMR obtained from the WoS core collection database.

The BMR in South Korea occupies a significant position in ecological research because of its designation as a biodiversity hotspot and its role as a crucial glacial refugium refuge for plant species (Chung et al. 2018a; Shin et al. 2021). In recent years, an increasing number of studies have focused on various facets of this mountain range, including changes in forest landscapes, village characteristics, plant species diversity and the impacts of climate change on species distribution (Choi et al. 2006; Dhakal et al. 2023; Kim et al.

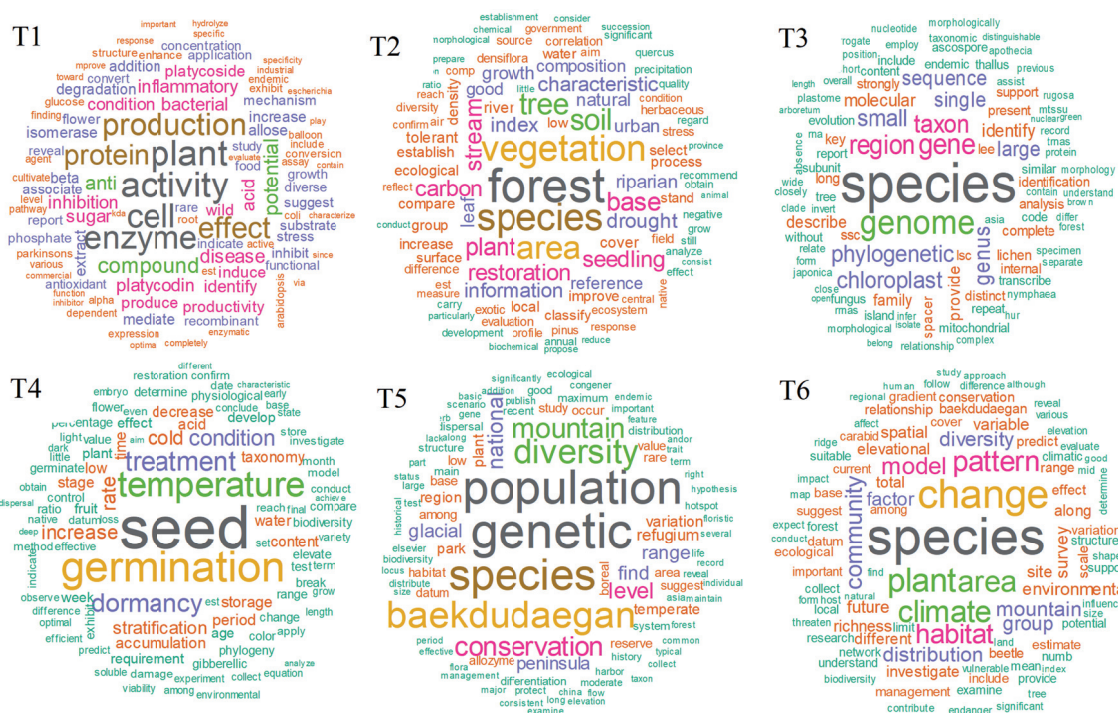


Figure 9 – Visualization of the 100 dominant words within each topic (T1 to T6). The size of each word represents its dominance based on frequency, whereas the colours are used to enhance readability and differentiate words visually.

2021; Kim et al. 2023; Park et al. 2022, 2017; Shin et al. 2021). We also observed that the most influential highly influenced literature focused on the species distribution, genetic diversity and glacial refugium characteristics of the BMR and the annual changes in year wise dominant thematic words within the literature highlighted the genetics, species, population and seeds as current focal points.

Mountain ecosystem research is increasing globally (Gurgiser et al. 2022; Liu et al. 2022). We also observed that Baekdudaegan-linked research has exhibited an increasing pattern, but one that appears to be in the early stages of research diffusion (Rogers 1983). The publication of Baekdudaegan-linked research followed an exponential trajectory with a rate of 0.34 WoS indexed publications in a year. This increasing trend could be of growing interest in investigating the ecological, cultural and socioeconomic dimensions of the study region. Forest and mountain-related research is aligned with multiple disciplines of SDGs (Baumgartner 2019; Timko et al. 2018). We observed that the alignment of the examined literature was dominated by SDG 15 with a particular focus on biodiversity conservation and ecosystem management (UNDP 2021). By aligning research efforts with the broader framework of the SDGs, Baekdudaegan-linked research can contribute significantly to sustainable development outcomes, while fostering interdisciplinary collaboration and knowledge exchange (Bettencourt & Kaur 2011; Zimmermann et al. 2018).

We observed the research landscape linked to the BMR, dominant latent words, SDG alignments, research categories, contributing authors, institutions and LDA topics. This would support collaborative effort on local as well as global mountain studies. Similar WoS categories such as plant science and ecology were the leading clusters within Baekdudaegan studies as highlighted in the previous mountain-related research (Gurgiser et al. 2022; Liu et al. 2021; Mengist et al. 2020). Understanding research-contributing institutions supports resource and knowledge sharing (Mufungizi et al. 2023; Shen et al. 2023; Subramanyam 1983). The Baekdudaegan National Arboretum is the predominant contributing institution that has conducted numerous projects focused on in- and ex-situ conservation, and the use of biological resources (Baekdudaegan National Arboretum 2024). In addition, we employed visualization techniques to elucidate keyword networks, facilitating the identification of interdisciplinary keywords and revealing link-strength distributions (Van Eck & Waltman 2018).

The LDA model was fitted to the keywords and abstracts, suggesting that six topics provided insights into the current research trends in the forest dynamics of the BMR. The first LDA-modelled topic comprised words related to biochemical pathways and their impact on industries and health supplements. The second topic included complex forest ecosystems and myriad indices defining ecological balance related to compre-

hensive evaluations and strategies for forest conservation. The third topic consisted of genomic taxonomy and molecular identification across species, using molecular identification techniques related to deciphering evolutionary relationships and preserving diverse genetic lineages. The fourth topic covered seed physiology, germination dynamics and environmental factors related to agricultural practices, ecosystem restoration and conservation. The fifth topic covered mountain biodiversity conservation, genetic diversity and population genetics related to sustaining ecological balance in mountainous landscapes. The sixth topic comprised the species response to climate change and adoption, focusing on habitat distribution which is inclined to stress the urgency of setting strategies to mitigate the threats of ongoing environmental challenges.

Based on the distribution of dominant words in LDA, we have proposed six potential broad topics: 1) bioactive plant components, biochemical significance and disease; 2) forest ecosystem restoration by contrasting urban-natural dynamics; 3) genomic taxonomy for molecular insights and evolutionary significance; 4) seed germination dynamics and environmental factors; 5) mountain biodiversity and conservation strategies; and 6) climate-induced changes and species resilience that contribute to ecosystem services, ecological policy research and SDGs (Altaweel et al. 2019; Liu et al. 2022; Mengist et al. 2020). The WoS categorization of the analysed literature predominantly aligned with SDG 15. Additionally, the results from the LDA model reveal that topics primarily associated with SDG 15 often intersect with other SDGs, depending on their emphasis on aspects such as health, climate, ecosystems and sustainability. This convergence between the WoS report and LDA findings validates the consistent association of the topics with the SDGs, highlighting the importance of BMR research for sustainable biodiversity conservation and land management.

Although the current study explores research insights gained from the publication trends and thematic structure of BMR linked studies, it has several limitations. The inherent limitations of bibliometric and LDA topic modelling methods is their inclination towards data-driven research outputs rather than specific content. This study relied only on the WoS database, missing valuable information from other sources such as Google Scholar, Scopus and the Korean Science Index (KSCI). Although there are biases, bibliometric studies explore various insights such as authors, institutional and document contents (Donthu et al. 2021). We examined publication trends, article keyword networks, contributing institutions and the 2030 agenda for the SDG alignment, as suggested in the WoS database. In-depth research on science mapping, research performance and network analysis of all scholarly sources can influence the results. Furthermore, the study employs LDA modelling, defining six topics concerning current research trends that may

oversimplify complex phenomena. Comparing different metrics and topic modelling approaches, such as non-negative matrix factorization (NMF) and latent semantic analysis (LSA), could achieve a more robust and nuanced examination of scientific content related to the Baekdudaegan mountain network.

This is a case study involving the Korean Peninsula. We have identified some noticeable areas for future research linking mountain ecosystems such as climate change impact and adaptation, biodiversity and conservation, ecosystem services, forest dynamics and restoration ecology, genetic diversity and evolution, anthropological impact and conflict mitigation and ecological monitoring and data generation that can enhance understanding and management (Blatter et al. 2017; Canedoli et al. 2024; Shen et al. 2023). The increasing BMR research centred on biodiversity and nature has contributed to South Korea achieving the seventh position on the 2023 Nature Index (NI). NI is examined based on research publications in 82 natural science journals selected by an independent group of researchers (Woolston 2023). Upgrading the national NI rank would be a future goal for researchers in this region. The Man and Biosphere Program (MAB) of UNESCO has established fundamental principles and methodologies for proficiently governing the Biosphere Reserve, necessitating ecological research and conservation endeavours to uphold biodiversity and sustainable practices (Batisse 1982). In the keywords network of this study, terms such as *protected area*, *Biosphere Reserve*, and *Korea* are cohesively clustered, yet challenges persist in the incorporation of the BMR into Biosphere Reserve regions (Lee 2019). Examining social issues and contributing factors will be the next research path. Continuous research and development within the Baekdudaegan networks hold promise for achieving diverse objectives, serving as a crucial pathway towards enhanced ecological understanding, conservation efficacy and sustainable resource management. Future study could also be bibliometrically comparative, employing topic modelling on other locally and globally protected, as well as non-protected, mountain ranges in the world.

Conclusions

Mountain research has focused on the unique species and ecological characteristics of different mountain ranges worldwide. This study has explored insights into the research surrounding the BMR in the Korean peninsula applying bibliometric analysis and LDA modelling to the metadata of 165 WoS-indexed articles. We examined research trends and their alignment with WoS categories and the 2030 agenda for UN SDGs, co-occurrence networks, collaborating institutions and LDA topics. Overall, the results of the hybrid bibliometric analysis and topic modelling approaches of this study benefit local ecosystems and open avenues for studies across global mountain

networks. Beyond academia, this study encourages co-operation and knowledge exchange among researchers and policymakers to address challenging environmental issues and to promote sustainable management practices.

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Data availability

Raw data will be available at <https://Figureshare.com/s/f832b3cc6f17ce84207c> and as Supplementary File S1.

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The Evolution of the World Network of Mountain Biosphere Reserves (WNMBR) – Bridging Science and Practice for Sustainable Mountain Management

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Keywords: mountains, biosphere reserves, network, knowledge-sharing

Abstract

The World Network of Mountain Biosphere Reserves (WNMBR) was established in December 2021, making it one of the newest of the six thematic networks of UNESCO's Man and the Biosphere (MAB) program. The aim of the network, which currently consists of just over 80 mountain biosphere reserves, is continuously to support biosphere reserves in mountain regions through research, strategic partnerships and cooperation, innovative management practices and knowledge-sharing. The WNMBR is coordinated by the MAB Secretariat at UNESCO Headquarters in Paris and a joint technical secretariat run by the Research Centre for Eco-Environmental Sciences of the Chinese Academy of Sciences (China) and the Valles de Omaña y Luna Biosphere Reserve (Spain).

Background

The history of the World Network of Mountain Biosphere Reserves (WNMBR) is intertwined with efforts to integrate biodiversity conservation, sustainable development and scientific research in mountain areas around the world. Since the establishment of UNESCO's Man and the Biosphere (MAB) programme in 1971, interdisciplinary research on mountain ecosystems and the ecosystem services they provide has been one of the programme's priorities, resulting in several international projects and initiatives (Price et al. 2024). The reason for the growing interest in mountain regions is obvious: mountain regions cover around 22% of the earth's surface, are home to around 15% of the world's population (currently around 915 million people) and are rich in cultural and biological diversity. About half of the world's biodiversity hotspots are found in mountain areas (Payne et al. 2020; WNMBR 2025).

At the time of its inception, the MAB programme focused on 14 research themes to achieve the programme's goals of exploring and protecting the world's most important ecosystems. One of these research themes was the MAB-6 project, which focused on monitoring the impact of human activities on mountain and tundra ecosystems, with strong roots in international interdisciplinary mountain research (Köck & Grabherr 2014; Price et al. 2021). MAB-6 quickly attracted attention, became one of the priorities of the MAB programme and served as a catalyst for research initiatives, knowledge exchange and collaboration on mountain issues. One of the most important sub-projects of MAB-6 was the MAB meta-project Obergurgl, which was dedicated to the study of the ecosystem of the municipality of Obergurgl (Tyrol, Austria) in all its ecological and socio-economic components from 1973 to 1980 (Moser 1975, 1987; Köck & Grabherr 2014; Köck & Arnberger 2017; Scheurer 2020; Price et al. 2021).

Two other important projects took place in the 2000s, which provided, so to speak, the model for the founding of the WNMBR, namely GLOCHAMORE (Global Change in Mountain Regions 2003–2005) and its successor project GLOCHAMOST (Global Change in Mountain Sites 2009–2011).

GLOCHAMORE, which was probably the first research project of the MAB programme to deal with global change in biosphere reserves (BRs), produced the *GLOCHAMORE Research Strategy* as an outstanding result, in which 10 key areas for research were highlighted to steer the sustainable management of these areas. In the follow-up project GLOCHAMOST, this research strategy was to be put into practice. The key areas addressed were implemented in a total of nine mountain BRs (M-BRs) (Price et al. 2021, 2024; Schaaf 2009). The research strategy has been used in subsequent years for work in BRs and has also led to further initiatives and projects. However, its existence / importance has been somewhat forgotten in the last decade, although the demand for scientific support for the management of M-BRs and a better exchange of information and experience has steadily increased.

Spurred on by the ever-increasing challenges of global change for the managers of M-BRs, a small group of scientists and BR experts, led by M. Price (UHI Perth), together with the MAB Secretariat in Paris, developed the idea of establishing a network for M-BRs, based on the achievements of GLOCHAMORE and GLOCHAMOST, but adapted to the current challenges. If it were possible to bring together as many BRs as possible in a network to share experiences and conduct research on specific mountain issues, such a network could improve the role of M-BRs and represent an important strategic tool for UNESCO to promote cooperation between Member States and support them in implementing the UN Sustainable Development Goals (SDGs) and the International Environmental agreements on biodiversity and climate change.



Figure 1 – Participants of the first face-to-face WNMNR meeting in the Valles de Omaña y Luna BR (Spain). From left to right: Yi Zhiyun, María Rosa Cárdenas Tomažič, Xu Weihua, Jorge Sánchez-Cruzado, Francisco José Cantos Mengs, Günter Köck, Claudia Köck, Carolina Adler, Roberto Aquerreta, Guillermo Castiñeira, Natalia Castro, Thomas Schaaf, Paola Fontanella Pisa, Natalia Beltrán, Wenlu Cheng, Zhiyun Ouyang

Even in the initial discussions, it was agreed that this network should have a strong scientific component to support management, facilitate science-based decision-making and generate a significant impact in the territory through projects and activities. To achieve this, it was deemed essential to have a technical secretariat to serve as both the driving force and an information hub. Additionally, securing a budget to fund activities and projects was identified as a key requirement. The administration of the future network was therefore envisioned to follow the successful model of the World Network of Island and Coastal BRs (WNICBR) coordinated by the MAB Programme in collaboration with two technical secretariats funded by the Republic of Korea and Spain (Jeju Island and Menorca Island respectively).

In June 2021, the MAB Secretariat invited all interested UNESCO Member States to submit applications for the position of Technical Secretariat. These applications were reviewed by the MAB Bureau, which ultimately selected the proposals submitted by the People's Republic of China and Spain.

During the meeting of the Bureau members, Austria recommended accepting both applications for strategic reasons. This would have the advantage that the proposed candidates together would include a greater variety of working languages (Chinese, English and Spanish), different mountain chains in different regional groups (Asia-Pacific, Europe and Latin America and the Caribbean) and open cooperation with several existing regional MAB networks (e.g. EuroMAB, IberoMAB, East Asia Biosphere Reserve Network [EABRN]). In addition, the two candidates would represent two main pillars of the MAB community, namely Academia and BRs (UNESCO 2021). Austria's proposal to nominate the Research Centre for Eco-Environmental Sciences of the Chinese Academy of Sciences and the Valles de Omaña y Luna BR for the joint coordination of the Technical Secretariat in co-



Figure 2 – Group photo from the 1st Workshop of the World Network of Mountain Biosphere Reserves in Dujiangyan (China).

operation with the MAB Secretariat was unanimously accepted by the Bureau members (UNESCO 2021).

The official launch of the WNMNR took place on 9 December 2021 during a webinar on *Sustainable Tourism in Mountain Biosphere Reserves* organized by UNESCO's MAB Programme and the Mountains Research Initiative (MRI) as part of the International Mountain Day celebrations (MRI 2021).

At this point, it should be noted that many MAB documents and media articles referred to the process as a relaunch, which does not quite reflect the reality. Although GLOCHAMORE, for example, involved over 140 scientists from all over the world in addition to UNESCO and 11 research institutions (Price et al. 2024), the project was not a genuine thematic network, but *only* a research collaboration, albeit a global one. Although the WNMNR builds on the results and spirit of GLOCHAMORE and GLOCHMOST, its establishment should therefore de facto be regarded as a new foundation.

Shaping the working structures

In January 2022, the first online meeting of the WNMNR Secretariats and its advisory board made up of experts on BRs and mountain regions discussed the creation of an initial roadmap for the implementation of the network.

Although communication between the stakeholders was considerably impaired by the Covid situation at the time, the establishment of the structures progressed quite quickly. Even before the tender for the Technical Secretariat, a list of members of the World Network of Biosphere Reserves (WNBR) provided by the MAB Secretariat was used to determine the proportion of M-BRs in the World Network of Biosphere Reserves.

Two problems immediately became apparent. One of these was that the geographical coordinates of the respective BRs had been entered incorrectly in some cases, presumably due to frequent editing by different editors, so that the BRs were sometimes incorrectly positioned by several hundred kilometres in a map produced by the Institute of Interdisciplinary Mountain

Research of the Austrian Academy of Sciences, which necessitated a time-consuming revision of the list.

The main challenge, however, was that no clear definition of an M-BR existed then or now for membership of the network. Deciding whether a BR on the World Network of Biosphere Reserves list also counted as an M-BR was therefore very difficult in several cases.

Mountains and mountain regions were and are difficult to define, which is why numerous definitions exist today. Currently, the most used approaches to define mountains are those found in Kapos et al. 2000, Körner et al. 2011, 2021 and Karagulle et al. 2017. These approaches use combinations of geomorphometric parameters such as elevation, slope and ruggedness or relief, which are nowadays derived from digital elevation models, and attribute thresholds to decide which terrain is mountainous and which is not (Körner et al. 2021). In addition, consultation with some BR management teams revealed that a BR's self-perception also plays a decisive role in determining its membership in the WNMBR, that is, whether it considers itself as a mountain area or not. One example of this is the Austrian BR Wienerwald. The region is located in the north-eastern spurs of the Alps, is part of the Alpine network of the Alpine Convention and could therefore be considered to be a member of the WNMBR (Köck et al. 2009). However, due to its proximity to Vienna and the associated challenges, its management considers it more of an urban BR than an M-BR and therefore has not joined the WNMBR (A. Weiss, Wienerwald BR-Management, personal communication).

After discussion among experts, it was decided provisionally to use the self-description of the respective BR in its official registration, along with a minimum elevation of 1,000 m asl, to create a provisional list of M-BRs.

To improve public relations and communication within the network, the new WNMBR website was published in three languages (English, Spanish and Chinese) in September 2022. Three months later, the first biannual WNMBR newsletter was published.

Finally, after the end of the Covid pandemic and about two years after the launch of the network, the first face-to-face meeting of the Technical Secretariats and the Advisory Group took place in the Valles de Omaña y Luna BR (Spain) from 7 to 11 March 2023 (Figure 1). The participants drew up a work plan for the next two years, focusing on tackling global issues such as biodiversity loss and climate change to support the implementation of the 2030 Agenda for Sustainable Development.

The meeting participants agreed that tackling these significant global problems increasingly requires bridging the gap between policy, scientific research and indigenous and local knowledge.

In this session, the foundations and mission of the WNMBR were analysed in detail, as well as the way



Figure 3 – Group photo from the 2nd Workshop of the World Network of Mountain Biosphere Reserves in the Ordino BR (Andorra).

in which the work of the WNMBR should be structured. For the roadmap three main areas of work were identified:

- Research for actionable knowledge,
- empowerment and participation,
- support for adaptive management.

To realize these points, six initiatives were decided upon, to be launched immediately:

- Sharing small, affordable and creative initiatives to address global change at the local level.
- Exchanging tools for monitoring biodiversity and socio-economic dynamics.
- A communication platform for M-BR managers.
- A capacity building programme (for WNMBR members).
- A youth education and engagement programme.
- A catalogue of participatory approaches.

Furthermore, three working groups made up of WNMBR members were set up to work on three very important topics for M-BRs:

- Adaptation to climate change and resilience,
- biodiversity,
- participation and socio-economic aspects.

The new 2023–2025 roadmap was presented at the third WNMBR online meeting on 24 May 2023, where it was unanimously adopted by over 120 participants from at least 15 countries from all five continents.

A major milestone for the network was the first face-to-face meeting of the WNMBR held from 18 to 22 September 2023 in Dujiangyan (China). The event brought together around 60 participants, including representatives from M-BRs, related organizations, experts and academics from 17 countries. Key agenda items were the refinement of the new roadmap, first working group meetings and the presentation of a proposal for an exchange programme for BR staff, as well as an international internship programme for young researchers within the network.

Furthermore, several workshops were organized on the three main areas of work in the road map. The aim was to develop a methodology to identify best practices and their replicability and scalability within

the network. In addition, 10 best practice examples selected from a total of 50 projects implemented in M-BRs were presented.

To strengthen the cohesion and functionality of the network, an annual calendar of formal meetings has been agreed upon, consisting of one face-to-face meeting and two online meetings, along with those convened by the working groups. This ensures continuous communication between members and enhances cooperation between M-BRs.

From 24 to 27 September 2024, the second WNMBR face-to-face meeting took place in the Ordino BR (Andorra). This very fruitful event gathered around 50 participants from 22 countries, focusing on strengthening the network, refining the 2025 roadmap, reviewing progress from the past year and defining new lines of action for the future. Prior to the meeting, a questionnaire was sent to all WNMBR members to gather information on the current state of the network and suggestions for improvement. The results provided valuable information on the needs and challenges of the network, which were integrated into the strategic planning.

Participants addressed important topics such as the internal organization of the network, the expansion of membership and ongoing or planned cooperation initiatives.

Status quo of the WNMBR and next steps

Some important conclusions were drawn from the intensive discussions at the WNMBR meeting in Andorra, which will be incorporated into the 2024–2025 roadmap and should now be implemented or tackled immediately.

Strategic roadmap

Clear priorities for the 2024–2025 period have been identified, including defining the network's mission, vision and values and creating a five-year strategic plan. The need to develop impact indicators that demonstrate the contribution of M-BRs to conservation, sustainability and socio-economic development was also emphasized.

Consolidation of the network and definition of mountain biosphere reserves

The network currently comprises 83 BRs in 37 countries in Africa, Arab States, Asia/Pacific, Europe, North America and Latin America/Caribbean. The WNMBR is thus clearly on the way to greater internal cohesion and geographical diversification. However, attracting more M-BRs from under-represented regions to join the network is still a priority. Strength is expressed in numbers! The more members, the stronger the external representation of the network, the greater the wealth of knowledge and experience within.

Furthermore, there is an urgent need to establish a clear and comprehensive definition of an M-BR for

network membership and for further analysis. To address this, the MAB Programme Secretariat has been working on a broader and more inclusive definition, moving beyond altitude as the sole criterion. This effort takes into account various existing definitions of mountains, as proposed in Kapos et al. 2000, Körner et al. 2011, 2017, Karagulle et al. 2017, and Snethlage et al. 2022.

Strengthening communication and cooperation

The opportunities for internal communication such as newsletters, digital platforms and regular webinars are to be expanded and improved. This should facilitate knowledge transfer and improve the visibility of the WNMBR in international forums.

Participation in international events

Right from the start, the network began to increase its participation in international events relevant to M-BRs, such as the First Southern African Mountain Conference 2022 in South Africa (Köck et al. 2022), the International Mountain Conference 2022 in Innsbruck (Austria) (Fontanella Pisa et al. 2022) and the World Biosphere Reserve and Global Geopark Sustainable Development Conference 2024 in Changbaishan (China). For example, a workshop on *Climate change and mountain regions* was organized as part of the EUROMAB Conference 2024 in Wittenberg (Germany), in which experiences from M-BRs were exchanged (Strasser & Köck 2024).

The World Congress of Biosphere Reserves 2025, which will take place in Hangzhou (China) in the third week of September 2025, is an important event for UNESCO's MAB programme, as it will lay the foundation for the programme's new 10-year strategy. The World Congress represents an important strategic opportunity for the WNMBR to position the network as a reference for sustainable mountain management. The network will therefore use this space to make its influence visible and strengthen international partnerships.

Innovative and cooperative projects

Several projects have been discussed and prepared in the last two years. These are intended not only to promote the creation and exchange of knowledge, but also to strengthen local and regional capacities to tackle global challenges.

Launch of a GLOMOS-WNMBR internship programme

This programme will connect young researchers with M-BRs, facilitating the integration of scientific knowledge into biosphere reserve management. The project will be launched in 2025 in collaboration with EURAC Research (Bolzano, Italy) and The United Nations University as part of the GLOMOS (Global Mountain Safeguard Research) programme.

Launch of an exchange programme for mountain biosphere reserve staff

The aim is to facilitate knowledge exchange between M-BRs and to promote collaboration, innovation and capacity building. The programme is intended to start in summer 2025 as a pilot project with the exchange of technicians and/or managers between the Nockberge (Austria) and Ordino (Andorra) BRs.

Contribution of mountain biosphere reserves to biodiversity conservation

The Research Center for Eco-Environmental Studies of the Chinese Academy of Sciences is working on a project to measure the contribution of World Network of BR to biodiversity conservation, sustainable development and climate change mitigation. For example, a set of key indicators and a baseline will be defined to facilitate subsequent measurement and monitoring. Data is currently being collected from all BRs in China, but the project will be expanded to cover the entire globe in the future.

Glacier monitoring and conservation project

This project aims to inventory glaciers in the M-BRs and encourage citizen participation in their conservation using a citizen science tool. It will define a baseline for the presence of glaciers in the WNMBR and collect testimonies on the biocultural relationship of people and local and indigenous communities with glaciers, whether they are present or have disappeared. The project shall contribute to the United Nations International Year of Glacier Conservation 2025 and the Decade of Cryosphere Research 2025–2035.

Cultural giants

This initiative seeks to document and promote traditional cultural expressions in M-BRs through digital and printed publications. So far, 16 cultural expressions from six countries have been collected.

Conclusion

Since its creation, the WNMBR has rapidly evolved into a key global player in the conservation and sustainable development of mountain ecosystems. Important reasons for the rapid progress since its creation have undoubtedly been the engagement of its technical secretariat and the establishment of a highly committed advisory group. Another factor could also be the fact that all face-to-face meetings are led by the same experienced facilitator who knows the network and its stakeholders very well.

In the future, it would be desirable for the Technical Secretariat to count on its own budget to cover structural costs, as well as to finance network-wide projects and activities. Furthermore, efforts must be made to accelerate the process of recruiting new members, especially from previously under-represented regions. In addition, a clear definition of an M-BR for member-

ship of the network must be established as soon as possible.

Building on the success of previous initiatives such as GLOCHAMORE, the World Network of Biosphere Reserves will continue to forge partnerships, share knowledge and promote strategies that secure the future of mountains and the people who depend on them. With new initiatives, the network will help M-BRs adapt to the challenges of the future, including climate change, while ensuring that M-BRs and their societies remain vibrant, sustainable and resilient to future uncertainties.

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Glaciers and glaciation changes in the Hohe Tauern National Park (Austria): From early research initiatives to glacier preservation

Gerhard Karl Lieb & Andreas Kellerer-Pirklbauer

Keywords: glaciers; glacier research; glacier monitoring; glacier preservation; Hohe Tauern National Park

Abstract

The Hohe Tauern National Park (HTNP) is Austria's largest (1,856 km²) and oldest (1981) national park with some of the highest peaks in the Eastern Alps. Some 19% of the present national park was covered by glaciers during the Little Ice Age maximum circa ad 1850. One third of this area is still covered by glaciers. This paper presents a short overview of the long glaciological research tradition and the monitoring activities on glaciers starting in 1879 and presents selected results from the HTNP. In addition, the importance of glaciers for the HTNP is discussed with special emphasis on educational trails. Some considerations on aspects of glacier protection conclude the article.

Profile

Protected area

Hohe Tauern

National Park

Mountain range

Alps, Austria

Introduction

The United Nations has declared 2025 the International Year of Glaciers' Preservation to point out the global importance of glaciers. This declaration is accompanied by the proclamation of 21 March of each year as the World Day for Glaciers starting in 2025. The aim is to raise awareness of the crucial role of glaciers, snow and ice in the global climate system and water cycle and to increase awareness of the economic, social and ecological impacts of impending changes in the Earth's cryosphere (UNESCO 2025). Numerous events and publications all over the world contribute to this effort, as for instance listed by the World Glacier Monitoring Service (WGMS 2025a). As glaciers are endangered by climate change, glacier protection and preservation may first mean climate change mitigation – including all well-known societal, political and economic challenges. However, a second aspect of glacier preservation, which plays a crucial role in this text, is tied to the aspect of nature conservation. This implies protecting glaciers and surrounding areas from being changed or even destroyed for economic reasons. In the European Alps (hereinafter referred to as Alps), these primarily comprise the construction and maintenance of power plants and touristic infrastructure. Like other ecosystems, only (high) mountains with no or little technical impact ensure the supply of the ecosystem services of glaciers such as water release, natural hazard mitigation, aesthetic values and tourism.

Against this background, this article is dedicated to an exemplary Austrian mountain region in which glaciers are frequent, important for society and well protected in terms of nature protection. The widespread glaciation is due to high elevations along the central crest of the Alps, including Austria's highest summit (Großglockner, 3,798 m asl). This is among the aspects which aroused the interest of scientists

and alpinists at the turn of the 18th and 19th centuries. Glacier research began in the mid-19th century and glacier monitoring a few decades later. The latter has continued ever since. This resulted in long time series of monitoring data giving detailed insights into glaciation changes since the last glaciation maximum during the Little Ice Age (LIA) circa 1850. The idea of nature conservation intensified from the 1970s onwards and led to the establishment of the Hohe Tauern National Park (HTNP) in 1981 with substantial expansions in 1984 and 1992. This paper presents a short outline of different topics on glaciers and their variations based above all on long-term monitoring results and ends with some remarks on glacier preservation.

Glaciers in the Hohe Tauern National Park

Glaciers are widespread in the HTNP (Figure 1). At the glaciation peak of the LIA, all glaciers in the present-day national park covered an area of 352.8 km² (100%), in 1969 of 206.5 km² (58.5%) and in 2015 of 126.6 km² (35.9%). The percentage of glacier areas in the HTNP (overall area 1,856 km²) amounts to 6.8% in 2015 compared to 11.1% in 1969 and 19.0% in 1850. Thus, only one third of the former glaciated areas are still left (and substantially less of the volume). For comparison, between the LIA maximum and 2015 the glaciated area in all of Austria was reduced from 941 km² (Fischer et al. 2015) to 330 km² (Buckel & Otto 2018), i.e., by about two thirds. For the same time period, Reinthaler & Paul (2025) show that for the entire European Alps the glaciated area has shrunk from 4,244 km² to 1,806 km² (–57%) and the volume has decreased from 280 km³ to 100 km³ (–64%). The mountain areas with the largest glaciers are around the summits of Großglockner, Großvenediger, Hoher Sonnblick and Hochalm Spitze (Figure 1b). Some of the glaciers are famous due to their size and scenic beauty in combination with mountain summits which

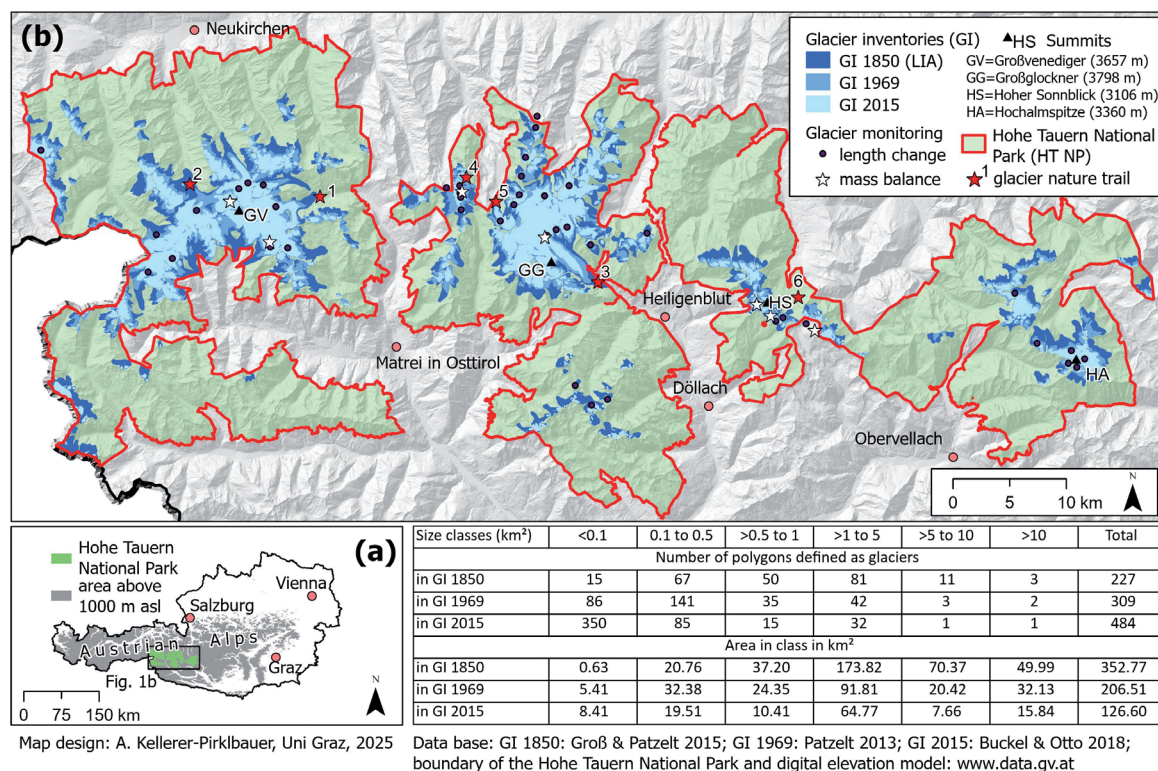


Figure 1 – Map of Hohe Tauern National Park (HTNP) in Austria (a) and its glacier extents (b) according to different glacier inventories (GI) for 1850, 1969, and 2015. The absolute number and area of glaciers per size class are given in the inset table. Glaciers with length changes and/or mass balance is monitored are indicated. Educational glacier nature trails: 1 = Schlattenkees (Innergschlöß), 2 = Obersulzbachkees, 3 = Pasterze, 4 = Stubacher Sonnblickkees, 5 = Ödenwinkelkees, 6 = Goldbergkees.

are among the highest in Austria. As will be explained in the section *History of glaciological research* of this article, those glaciers attracted early scientific attention – above all the Pasterze Glacier, Austria's largest, situated beneath Großglockner. During the LIA, valley glaciers were widespread. In the central part of the Venediger and Glockner mountains, almost every valley was covered by a mighty glacier tongue. Meanwhile, most of the glacier tongues have disappeared so that mountain glaciers covering high-elevated cirques became the typical glacier type.

History of glaciological research

The first reports about the glaciers of today's HTNP date back to the 17th century. In the LIA period, 15 large glaciers tongues advanced to elevations lower than 2,000 m asl even affecting pastures there (Groß 2018). Some glaciers – above all the Nördliches Bockkarkees (*Kees* is the regional term for glacier) – caused damage by ice avalanches (Kellerer-Pirklbauer et al. 2012), whereas lake outburst floods (like in the Ötztal Alps) only occurred at small scales due to less critical topography (i. e., no damming of main valleys). The first glacier which attracted scientific attention was the Pasterze glacier. A. & H. Schlagintweit (1850) published a book with a map of this glacier. The map depicts the glacier extent in 1846 and is considered to be one of the oldest maps of a glacier in the Eastern

Alps. In 1879, F. Seeland set up control points in the proglacial area to quantify the annual front variation of Pasterze. Since then, those measurements have been carried out annually, except for in three years, resulting in the longest data series of glacier length changes in the entire Alps based on on-site measurements (Lieb & Kellerer-Pirklbauer 2018). More details about the glacier's cultural and research history can be found in the monograph by Lieb & Slupetzky (2011).

Examples of other large glaciers with a long research tradition are the Obersulzbachkees, the Schlattenkees and the Karlinger Kees. The names of the two famous Austrian researchers F. Simony and E. Richter are associated with glaciers in the HTNP. A glacier and two mountains in the Venediger Mountains were named for instance after Simony in his honour. All these activities contributed significantly to the glaciers becoming known. Furthermore, after the opening of the meteorological observatory on the summit of Hoher Sonnblick (3,105 m asl) in 1886, the glaciers in the surrounding Goldberg Mountains became objects of early glaciological research. The uninterrupted meteorological time series of this observatory serves as a frequently used reference for correlating glaciation changes with measured temperature and precipitation data (e. g., Kellerer-Pirklbauer et al. 2008).

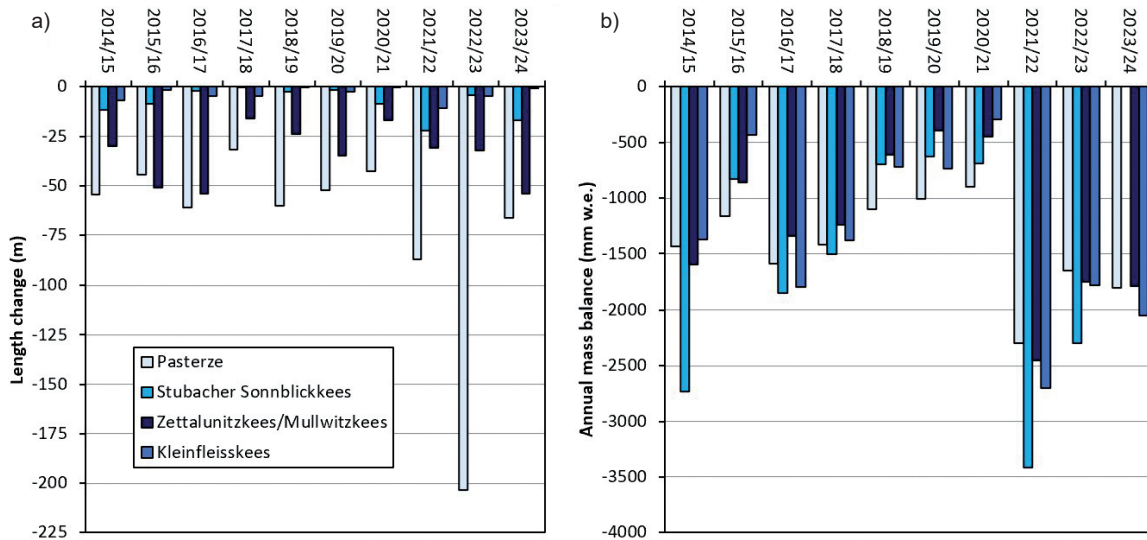


Figure 2 – Glacier monitoring results in the HTNP: (a) Length variation (in m) of four selected glaciers and (b) specific annual mass balances (in mm water equivalent/m.e.) of the same glaciers in the 10-year period 2014/15 to 2023/24. Data sources: (a) Austrian Alpine Association; (b) WGMS (2025b).

Modern glacier monitoring and its results

F. Seeland's pioneering work in setting up control points in front of the Pasterze Glacier in 1879 marks the beginning of modern glacier monitoring. At the turn of the 19th and 20th centuries already 26 glaciers in the later HTNP had control points for annual measurements of the length variations in their forelands (Groß 2018). This was basically the result of a letter published in 1891 by the former German and Austrian Alpine Association which encouraged its members to measure the glaciers regularly. Over time, this developed into the glacier monitoring service (*Gletschermessdienst*) organized and financed by what is now the Austrian Alpine Association (*Österreichischer Alpenverein*, OeAV). In 2024, the volunteers working for this service made available the results for 38 glaciers in the HTNP (Lieb & Kellerer-Pirklbauer 2025). Between 2023 and 2024, 37 glaciers retreated and only one did not significantly change the position of its terminus during this one-year observation period. The length variations of four selected glaciers are shown in Figure 2a. In addition to length variation, at the Pasterze Glacier variations in thickness and surface movement are also measured (Lieb & Kellerer-Pirklbauer 2025).

In 1963, H. Slupetzky for the first time measured the glacier mass balance at Stubacher Sonnblickkees. Over the years, the number of sites where mass balance measurements were carried out expanded. In 2025, mass balance data for seven glaciers in the HTNP were available from the World Glacier Monitoring Service (WGMS 2025b). Results for the last decade are shown in Figure 2b, which allows the comparison of length variations and mass balances for the same glaciers. Both diagrams impressively depict massive glacier shrinkage mainly as a result of exceptionally warm summers without snowfall events, in some years also

combined with little snow accumulation even in winter. The glaciers of the HTNP are no exception in the ongoing global deglaciation (WGMS 2025b).

The importance of glaciers

Numerous large and small glaciers are a characteristic feature of the HTNP. Glaciers have shaped and transformed the landscape for millennia. Even though these ice bodies are shrinking significantly due to climate change, they remain something very special. In addition, the glacier forelands are a primeval landscape that is repopulated by animals and plants (HTNP 2025). With a similar text content, the HTNP introduces visitors to the topic of glaciers and water. The text covers various aspects of the significance of glaciers:

- Glaciers shape the relief of the Alps – not just for millennia, but for at least 2.6 million years.
- Great number and spatial distribution make glaciers one of the dominant surface types of the HTNP (Figure 1).
- Glaciers are indeed *something very special* in terms of their rapid and very visible response to a changing climate.
- Not only the moraines, but the entire proglacial areas or glacier forelands are *primeval landscapes* in which geomorphological, hydrological and biological processes of high scientific value take place.

From a societal perspective, glaciers act as landmarks, are tourist attractions and contribute to creating regional identity. Therefore, they already played a crucial role in the period in which the HTNP was established – together with famous mountains and natural rivers, as well as animals and plants worth protecting. Thus, it may not be surprising that the core area

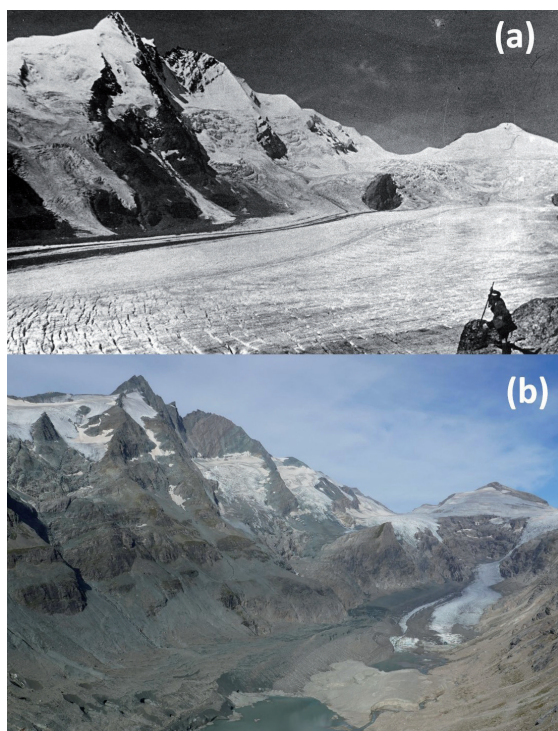


Figure 3 – The Pasterze Glacier, as it can be seen from the famous observation spot at Franz-Josefs-Höhe: (a) circa 1920 (Source: archive Gerhard Lieb) and (b) in September 2024. © Gerhard Lieb

of the oldest part of HTNP, which was declared a national park in 1981, was the Pasterze Glacier (Figure 3) and its at that time still widely glaciated vicinity. Aside from that, the HTNP celebrated its 30th anniversary among others with the publication of a book about the same glacier (Lieb & Slupetzky 2011).

Besides nature protection, the HTNP aims at scientific research, environmental education and regional development. The latter is to a minor extent the focus of the NP authorities, but more the focus of the local and regional stakeholders who try to make economic profit with the help of the HTNP. This is not necessarily a contradiction as the example of glaciers shows. Glaciers are valuable objects for environmental education as they make the relationship between climate and ice, as well as other natural processes, clearly visible. Moreover, glacial landscapes provide impressive scenery, not least due to the presence of water and the already mentioned natural dynamics in the proglacial areas. For this reason, of the first five educational trails established between 1978 and 1987 in the present-day area of the HTNP, no fewer than three led through the foreland of glaciers (1978 Innergschloß; 1984 Pasterze; 1986 Obersulzbachtal). The educational trail to the Pasterze Glacier (the first version of the trail in 1984; two updates afterwards) was one of the first educational projects to vitalize the young protected area of the HTNP in Carinthia, founded in 1981. Meanwhile there are six educational trails dedicated to glaciers and glaciation change in the park (Figure 1), each

of them offering guide books or comparable information. From a nature protection perspective, trails of this kind are considered a positive contribution to visitor guidance. From an economic point of view, they are tourist attractions. Educational trails are among the most important facilities of the HTNP because they provide authentic nature experiences outside the visitor centers.

Final remarks on glacier preservation

The conservation regime in HTNP – as in other IUCN Category I or II areas – makes special conservation measures for glaciers unnecessary, as all glaciers are located in the park's core zone, where no direct human intervention is permitted. However, this cannot, of course, prevent the glaciers from being exposed to global climate change. It should additionally be noted that large areas of the HTNP are owned by the OeAV. As Austria's largest environmental protection NGO, the OeAV guarantees the intact preservation of nature including glaciers on its property. As mentioned above, this cannot, however, reduce glacier retreat. Therefore, both the HTNP and the OeAV (together with other environmental organizations) use their facilities, publications and programs to enhance public awareness of climate change (together with other environmental challenges) and the necessity of climate change mitigation at all spatial scales from local to global.

Learning about climate change as a contribution to education for sustainable development is promoted in glacial environments: the experience of hiking combined with the acquisition of knowledge in an impressive landscape may allow for a deeper reflection on society-environment relationships, the recognition of personal responsibility and a sharpening of the view of political necessities. The latter encompass measures for both climate change mitigation and protection of near-natural areas, not only in the high mountains and beyond glacier and climate preservation. The well-investigated and well-protected yet shrinking glaciers of HTNP may convey this message to society.

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Wilderness at the centre – The new exhibition at the National Park Centre in Zerne

Hans Lozza

Keywords: wilderness, exhibition, national park

Abstract

The Swiss National Park (SNP) was founded in 1914 with the aims of protecting a piece of Alpine nature from human intervention and documenting its natural development. This extraordinary rewilding experiment required intensive public relations work from the outset, as the term *wilderness* did not and does not necessarily have positive associations among the local Alpine population. In order to make the ecological significance of wilderness accessible to the general public in an attractive way, in 2019 the SNP decided to create an extensive exhibition on the topic of wilderness at the National Park Centre in Zerne. Five years passed between the initial idea and the final installation of the new permanent exhibition, involving many phases of development and hurdles to overcome. This article documents the approach, planning and implementation of this important project for the SNP, which was officially opened to the public on 3 June 2023.

Profile

Protected area

Swiss National Park

Mountain range

Alps, Switzerland

Introduction

Pure wilderness is the message of the Swiss National Park (SNP). This is no coincidence: 111 years ago, forward-thinking pioneers conceived the revolutionary idea of a reserve in which all forms of life and natural processes are allowed to develop freely without human intervention (Kupper 2012) – an area where researchers endeavour to document and understand the changes that are occurring, but also where people can discover the importance of wilderness.

The National Park Centre is the ideal place to experience *pure wilderness* and *pure National Park* and actively to reflect on them at the same time. The exhibition aims to showcase the SNP's main themes of wilderness and natural processes, explaining the results of 100 years of research in the SNP and exploring not only the beauty, but also the primal and unforgiving aspects of nature and how we humans perceive them.

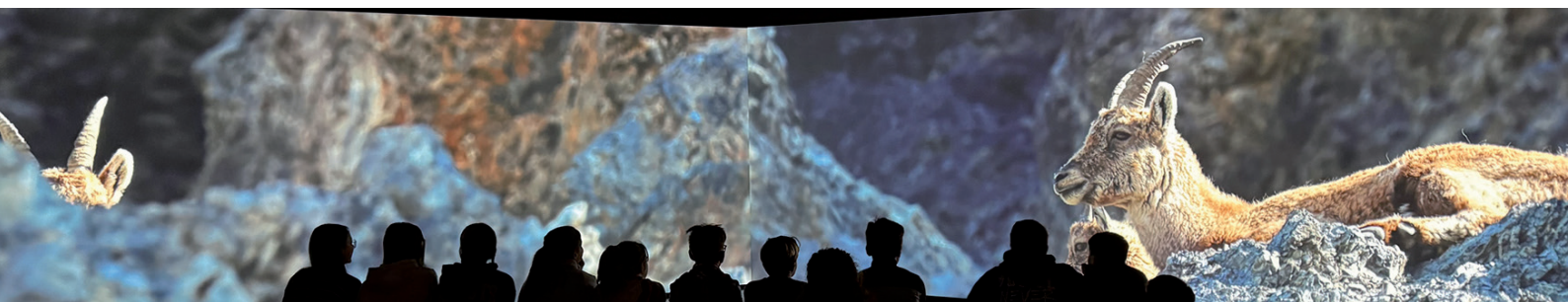
But what does wilderness mean for us as humans? What is our attitude towards it? And if we could personally determine it: how might wilderness evolve? Studies show that around half of the Swiss population have some reservations about wilderness (Hunziker 2000; Bauer et al. 2004; Bauer 2005; Moos et al. 2019). For the SNP and from an ecological point of view, wilderness is a place where nature can experiment and which experiences pronounced dynamics. As the

largest wilderness area in the Alps and a much-visited nature reserve, the SNP is the ideal place to experience the power of natural processes and biodiversity. Given this situation, it seemed obvious to capitalize on the allure of the SNP to develop an exhibition that allows visitors to explore their individual relationships with wilderness, the significance of wilderness (Gürke 2023) and our influences on such areas.

Finding the right partner

The success of exhibition projects depends on having the perfect team to plan and implement something new, spectacular and unique. At the beginning of the planning phase, we looked at the work of various companies and finally invited four of them to Zerne to present the exhibition space to be developed. In a collaborative discussion, the SNP project leaders set out their ideas and desires for the new exhibition, laying the foundation for the further exploration of exciting design ideas. Two months later, the companies submitted their exhibition ideas and presented them in person. Based on these presentations, we decided to work with Groenlandbasel. As part of the competition, their designers developed a convincing idea of how we could make wilderness accessible to all age groups. We also felt that we could work well with this team – a crucial point.

Figure 1 – The Panorama Room allows you to immerse yourself in unspoilt natural landscapes. © SNP, Hans Lozza



In order to develop an initial overview of the subject of wilderness, the SNP organized a wilderness workshop in February 2020. In addition to the SNP and Groenlandbasel, various organizations concerned with wilderness were represented. It soon became clear that we had set ourselves a challenging task, as the term wilderness does not evoke positive feelings in everyone. The importance of wilderness areas as hotbeds of biodiversity and protection of natural dynamics is often unknown. As the largest wilderness area in the Alps, the SNP wanted to raise awareness of this with the new exhibition. In doing so, it wanted to seize the opportunity to lead the wilderness discourse, improve the understanding of wilderness and encourage guests consciously to allow wilderness in their private surroundings. The foundations were now in place to embark on the adventure of a new production.

Target audience and levels of communication

Defining the target audience is central to exhibitions. In the case of the National Park Centre, this target audience is very broad: from small children to the elderly, from families and school classes to professionals. This challenging starting point requires a broad thematic approach with different levels of communication. Children of reading age will find clearly marked stations in the exhibition that invite them to play and discover (level 1). Young visitors aged 5 to 12 can experience the exhibition with a radio play accompanied by Furbina and Ratsch (level 2). The two Nutcracker siblings will keep young visitors busy throughout their visit to the exhibition. Finally, level 3 is for all other visitors. The aim is to offer each visitor a selection of individually appealing elements and let them choose what they want to engage with and in what depth.

To facilitate interaction with the public, a media guide was chosen as a means of communication. All visual and audio information is available in Romansh, German, Italian, French and English. When receiving their devices, visitors choose to follow either the child or adult track. The devices are equipped with headphones that do not touch the ears and thus enable communication with one another, e.g. within the family circle. The interactive device also offers the opportunity to answer questions and give feedback.

Scenography

In order to make the multifaceted SNP themes accessible and tangible, the staging makes use of strong contrasts and a broad spectrum of forms of communication. The sequence of four very different rooms and the personal exploration of the theme of wilderness based on questions builds up excitement. On the one hand, the tour offers immersive spatial displays and emotional experiences that can be shared with



Figure 2 – In the Wilderness Arena, guests are right in the middle of the production. © SNP, Hans Lozza

others. On the other hand, visitors can experience moments of individual contemplation at individual stations. Visitors determine the pace and amount of information for themselves. The content and form of the exhibition are always coordinated in such a way that everyone can quickly access the themes on their first visit, but can also discover something new on a return visit.

Kick-off: panorama and wilderness arena

In the first two exhibition rooms, visitors can immerse themselves in the wilderness and leave their everyday lives behind. The fascination of unspoiled nature and the power of the processes that shape the landscape take centre stage. Intimate moments are mixed with imposing impressions in a way that is designed to awaken personal emotions. Both rooms function as presentation rooms with very different approaches.

In the Panorama Room, guests can expect extraordinary perspectives and large-format snapshots from the wildest corners of the park. The 16-metre-wide screen covers the entire field of vision and allows visitors to dive into wilderness of the SNP. There is deliberately no human presence in the storyline, with the wilderness taking centre stage. The sounds created especially for the images unobtrusively accompany the natural events (Figure 1).

In the wilderness arena that follows, guests suddenly find themselves in the midst of the dynamic natural processes that characterize the SNP – an acoustic and visual spectacle. Whether standing in the middle of a forest fire, witnessing an avalanche or experiencing the spread of mushroom mycelium underground, the immediate proximity should get under your skin.

It was clear from the outset that *big cinema* would play a role at the centre. The previous exhibition had impressively demonstrated the positive impact of large-scale projections on the audience. However, we



Figure 3 – In the Open-Air Laboratory, guests become researchers. © Groenlandbasel, Cornelia Vinzens

also learned that inadequate acoustic separation has a negative impact on the quality of employees' workplaces. This is why the two new wilderness productions are located in soundproofed rooms.

Challenging film shoots

Developments in the video sector have been enormous over the last 15 years. While HD resolution was standard in 2008, today we are talking about 8K, i.e. 8 times higher resolution. For the SNP, this meant that most of the video material for the panorama room had to be reshot. For cost reasons, we decided to purchase 8K equipment and to tackle the filming with our own team and with the help of a dedicated intern. For the landscape shots, we used two cameras mounted on a plate covering a 180-degree angle of view. This resulted in synchronized panoramic shots with a corresponding overlap. The overall image is projected in the room by four projectors, which enables impressive sharpness with the chosen screen size.

By fair means was the basic principle of the production. The use of drones was deliberately avoided in order to minimize interference. For the animal scenes, it was important to us to show the animals in their undisturbed environment. This required large telephoto lenses and patience in order to create familiarity. The next step was to create a rough cut of the film. We discussed and further improved various versions within the exhibition team until we arrived at the final rough cut. The company Tweaklab took on the fine editing, colour correction and mastering, while the company *Idee und Klang* created the soundtrack.

What does the Swiss National Park sound like?

While the visuals take centre stage in the Panorama Room, sound is in the spotlight in the Wilderness Arena. The audience itself stands on the stage – amidst a

backdrop of sculptures made of solid and intensely fragrant Swiss stone pine. Animated projections (digital mapping) play on the scenery, creating a mystical spatial atmosphere. Guests experience first-hand the powerful processes that characterize the SNP. They also realize that they are exposed to these forces and cannot control them. This symbolizes the basic idea of the SNP, which is to allow natural dynamics to take charge and to study their effects. The backbone of the narrative is the multi-layered soundscape composed exclusively from real sounds, such as the rumble of thunder or crackling fire. Contrary to common practice, the soundscape was developed before the visual staging. Only as part of the second step did the three-dimensional, constructed stage develop, together with the plants and animals that appear, as well as the animated visual worlds. This approach challenged everyone involved but ultimately led to the uniqueness of the show's format.

The 16-channel sound in the Wilderness Arena (Figure 2) makes it possible to localize the source of the sound and direct the audience's gaze. As in the theatre, the audience's guidance is also supported by the spatial projections. The difference here is that visitors experience 360 degrees of immersion. The processes work from different directions and make the audience forget time and place.

Open-Air laboratory

After the two experience rooms at the beginning of the exhibition, visitors can look forward to a wealth of interactive stations in the Open-Air Laboratory (Figure 3). These provide insights into selected research projects and invite visitors to slip into the role of researchers themselves and to experiment. For example, it is possible to experience how various creatures such as the ptarmigan or butterflies react to climate change. Another module is dedicated to the effects of climate change on the landscape, for example on the activity of rock glaciers and debris flows. The Spöl module shows how artificial floods influence the dynamics and ecology of the Spöl stream. Here, visitors can trigger a flood themselves and actively experience its effects. In another module, a fence experiment simulates the 6th great extinction of species on earth. Finally, large predators also play an important role in the exhibition. Visitors learn about the methods used to research their impact on the ecosystem and are given the opportunity to try them out for themselves. In addition, a timeline shows the major milestones in park research. Finally, the tool wall presents the tools used by researchers in their daily work. They also talk about their work and their findings in videos.

Perspectives

The perspectives in the final room (Room 4) show how important wilderness is for our ecosystem and

what part we humans play in its development (Figure 4). In a large projection, visitors can experience how their behaviour and views affect the landscape. This is at once playful and realistic. Here we realize that we can make a personal contribution to the promotion of wilderness, even on a small scale.

This is possible thanks to the survey trail, which is a core element of the exhibition. Right at the start of the tour, guests are invited by a fictitious guide, via the media guide, to reflect on their own attitudes towards wilderness. The playful questions function independently of each other in terms of content and are loosely linked to the respective themes of the rooms. Answering the questions is not compulsory, but guarantees a fun personal exploration of the topic of wilderness, which comes to a surprising conclusion in the last room: visitors not only learn which of the five wilderness types they are, but they can directly experience how the SNP and its surroundings would change based on their wilderness type by means of panorama-like hidden object images.

The extensive development of the questionnaire, possible types of wilderness and the corresponding fictitious scenarios were supervised by experts and inspired by models from existing scientific studies (Bauer et al. 2009). The questionnaire was tested on 150 people in the summer of 2021.

Historical trail

Between the 4 rooms, a historical trail provides a central theme linking together the exhibition throughout the National Park Centre. In this vivid journey through time, visitors learn surprising facts about the milestones in the history of the SNP. The large-format illuminated pictures convey a picture of the relevant era and the acoustic presentation allows visitors to immerse themselves in a world that is almost unimaginable today.

Review

The majority of visitors' feedback on the new exhibition has been very positive. The two experience rooms in particular are very popular, but visitors also spend a lot of time in the Open-Air laboratory. There are always people who expect a nature museum to have as many animal specimens as possible. However, the aim of the new exhibition is deliberately to place the theme of wilderness at the centre in an experience-oriented and interactive way, thus distinguishing it from classic natural history museums with their own collections. From the point of view of the SNP and the scenographers, this has been very successful.

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Figure 4 – In Room 4, guests can experience how they shape the environment through their understanding of nature. © SNP, Hans Lozza

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Conservation and development of the Daqishan Nature Reserve in Hubei Province, China

Wen Xiong, Peter A. Bowler & Nan Li

Keywords: biodiversity conservation, forest ecosystem, highland, subtropical monsoon climate, endangered species

Abstract

The Daqi Mountain Provincial Nature Reserve in eastern Hubei Province, China sustains a unique natural forest ecosystem. It is an important reserve for the conservation of several endangered species and is a native highland forest habitat in the mountainous region of central China. Global warming, biological invasions and human disturbance are seriously threatening some of its endemic species and the entire forest ecosystem. Some endangered species, including *Chinemys reevesii*, *Hynobius chinensis*, *Paa boulengeri* and *Falco vespertinus*, have experienced significant stresses and ecological challenges. In order better to protect biodiversity and ecosystem functioning, some measures should be undertaken, including more research and ecological monitoring and the adoption of more reliable fire protection strategies and means of response. We hope that this study can provide useful information for the conservation and management of biodiversity in the forest ecosystems of central China.

Profile

Protected area

Daqi Mountain

Provincial Nature

Reserve

Mountain range

Dabie Mountains,
China

Introduction

Highland ecosystems sustain a high diversity of flora and fauna and a broad array of habitat types (Körner 2004; Perrigo et al. 2020), which support rich resources for human survival and sustainable development such as timber, food, medicine and diverse biological resources (Pender 2004; Rahbek et al. 2019). Global climate change, geological disasters, human disturbance, habitat destruction and biological invasions cause serious threats to these resources (Antonelli et al. 2018; Li et al. 2022; He et al. 2023). Because of these concerns and issues, researchers, governments and local residents direct significant effort to the conservation and exclusively sustainable uses of the biodiversity resources in mountain regions (Chen et al. 2009).

China has a very high number of mountains and large areas of montane regions which support a rich and unique biodiversity (Zhang et al. 2002; Tang et al. 2006). Biodiversity hotspots such as these are important refuges for many relict and endangered species (Mi et al. 2019). For example, the Yangtze River is one of 200 priority regions for biodiversity conservation, providing diverse habitats and sustaining high biodiversity (Olson & Dinerstein 1998). Unfortunately, accurate and current information about biodiversity is scant, which has limited effective management and conservation of biodiversity in some highland regions of the middle and lower reaches of the Yangtze River (Xiong et al. 2024).

Daqi Mountain is in the northeast part of Hubei Province, one of the richest biodiversity areas in Hubei Province with one of the best-preserved stands of forest vegetation in the southern foothills of Dabie

Mountain (Lei et al. 2012). The flora of Daqi Mountain has an ancient origin and is relict in nature. The Daqi Mountain setting concentrates and distributes many families and genera that are ancient in origin and primitive in systematic evolution, and it also contains many relict plants (Lei et al. 2013). For example, its ancient tree group of *Pinus hwangshanensis* are currently the species most well-protected in representative sites in central China.

The objectives of this study are to summarize the current status of the Daqi Mountain Provincial Nature Reserve's biodiversity and the factors influencing it, as well as to recommend appropriate conservation measures. We hope that this study will provide useful information and guidance for local governments and residents to sustain the existing biological resources in the highlands of the middle and lower reaches of the Yangtze River.

Study region

Hubei's Daqi Mountain Nature Reserve (DMNR) is located between 30° 47.57' – 30° 52.50' N and 115° 04.12' – 115° 10.07' E and is in the northern mountainous area of Tuanfeng County, Huanggang City, Hubei Province, China. The total area of the DMNR is 1,753.36 hectares, of which the core area comprises 629.81 hectares and the surrounding buffer area 389.95 hectares (Figure 1). The Daqi Mountain Forestry Farm was initially established in 1957 and the Daqi Mountain Provincial Forest Park was designated in 1993. On 31 May 2013, the General office of the People's Government of Hubei Province approved the establishment of the DMNR, with the primary protected elements being the northern subtropical

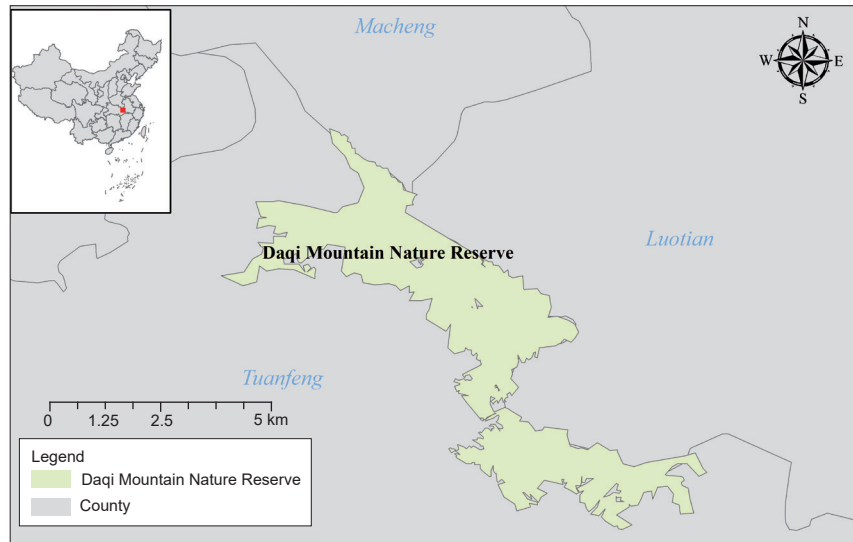


Figure 1 – The location of Daqi Mountain Nature Reserve. Data: Daqi Mountain Provincial Nature Reserve Management Committee.

forest ecosystem, endemic or endangered animal and plant species, such as the golden cat (*Pardofelis temminckii*), the Reeves' pheasant (*Syrnaticus reevesii*), and ancient tree communities of the Huangshan pine (*Pinus hwangshanensis*). The DMNR Management Committee was established in 1999.

The DMNR occupies the southern foot of the Dabie Mountains and the northern bank of the Yangtze River, lying climatically in the subtropical to temperate transition area. The DMNR is in low mountainous terrain with an elevation of 400–700 m. The mountain highland topography is oriented in an east-west direction.

The climate of the DMNR belongs to the subtropical continental humid monsoon climate category characteristic of the middle and lower reaches of the Yangtze River. The average annual precipitation is about 1,262 mm, with the highest reaching 1,784.8 mm in wet years, the lowest measurements of 789.1 mm occurring in dry years. The precipitation is concentrated in April, May and June and it is the lowest in winter. The average annual sunshine is 2,028 hours and the annual frost-free period is about 240 days. The average annual temperature is 16.8°C, the lowest temperatures occur in January, the average temperature is 3.9°C and the lowest temperature is –12.2°C. The highest temperature is in July, the average temperature is 29.3°C and the highest temperature is 40.3°C.

There are no large rivers or reservoirs in the DMNR, but it is the source of two large national reservoirs – the Daoguan River Reservoir in Xinzhou District, Wuhan City and the Niuche River Reservoir in Tuanfeng County. The rivers in the area are the Niuche River, the Bashui River, the Wugui River, the Longtan River and the Zhuizhi River, which all eventually flow into the Yangtze River.

Biodiversity status

Between 2011 and 2018 the authors, together with undergraduate students, conducted botanical and faunistic field practice courses in the DMNR. From 2019 to 2022, the botanical and faunistic field practice had to be cancelled due to COVID-19 restrictions. Unfortunately, in 2023–24, the park infrastructure was dismantled in order better to protect nature and biodiversity in the DMNR (Tuanfeng County Government Website 2024), so, botanical and faunistic field practice could not continue.

During the courses, we carried out various methods of botanical survey. In 2011–14, botanical surveys were conducted along all major tourist routes. In 2015–18, we carried out botanical surveys in 200 line transects (500 m per line). All plant samples were collected and identified according to *Flora of China*. Meanwhile, we conducted faunistic surveys between 2011 and 2018; for the detailed investigative method, see Wang et al. (2021).

Based on our field investigations between 2011 and 2018, there are 1,119 vascular plants species belonging to 581 genera in 168 families that occur in the DMNR. Within this flora there are 72 fern species in 41 genera and 25 families, and 1,047 spermatophyte species in 540 genera and 143 families (including 16 gymnosperm species in 13 genera and 6 families, and 1,031 angiosperm species in 527 genera and 137 families).

There is a high faunal biodiversity in the DMNR including 18 amphibian species (2 orders, 6 families and 8 genera), 29 reptile species (2 orders, 10 families and 22 genera), 144 bird species (14 orders, 37 families and 91 genera) and 42 mammal species (7 orders, 18 families and 35 genera).

It is worth noting that there are a great number of endangered species and ancient trees that have survived in the DMNR. Within the DMNR there are 31

Table 1 – Endangered plant species in the Daqi Mountain Nature Reserve.

No	Scientific name	State key protected plants	National rare and endangered protected plants
1	<i>Ginkgo biloba</i>	I	II
2	<i>Huperzia serrata</i>	II	
3	<i>Magnolia officinalis</i>	II	III
4	<i>Magnolia officinalis</i>	II	III
5	<i>Liriodendron chinense</i>	II	II
6	<i>Cercidiphyllum japonicum</i>	II	
7	<i>Fagopyrum dibotrys</i>	II	
8	<i>Glycine soja</i>	II	III
9	<i>Phellodendron chinensis</i>	II	
10	<i>Panax pseudo-ginseng</i> var. <i>Japonicus</i>	II	
11	<i>Fritillaria anthuisensis</i>	II	
12	<i>Fritillaria hupehensis</i>	II	
13	<i>Paris delavayi</i>	II	
14	<i>Paris polyphylla</i>	II	
15	<i>Paris polyphylla</i> var. <i>stenophylla</i>	II	
16	<i>Bletilla striata</i>	II	
17	<i>Cangnienia amoena</i>	II	
18	<i>Cymbidium ensifolium</i>	II	
19	<i>Cymbidium goeringii</i>	II	
20	<i>Cypripedium japonicum</i>	II	
21	<i>Gastrodia elata</i>	II	
22	<i>Phoebe zhennan</i>	II	III
23	<i>Zelkova schneideriana</i>	II	
24	<i>Emmenopterys henryi</i>	II	II
25	<i>Eucommia ulmoides</i>		II
26	<i>Changnienia amoena</i>		II
27	<i>Pteroceltis tatarinowii</i>		III
28	<i>Stewartia sinensis</i>		III
29	<i>Euptelea pleiosperma</i>		III
30	<i>Litsea auriculata</i>		III
31	<i>Dipteronia sinensis</i>		III

plant (Table 1) and 37 animal species (Table 2) that are listed as Category I and II Protected Species in China. In addition, there are 786 extremely old trees (including *Pinus hwangshanensis*, *Ginkgo biloba*, *Camphora officinarum*, *Pinus massoniana*, *Liquidambar formosana*, *Platycladus orientalis*, *Pterocarya stenoptera*, *Fraxinus chinensis*, *Castanea mollissima*, *Sophora japonica*, *Koelreuteria bipinnata*, *Quercus acutissima*, *Celtis sinensis*, *Quercus glauca* and *Diospyros kaki*) that have survived in the DMNR (including 10 trees over 500 years, 50 trees between 300 and 500 years and 726 trees between 100 and 300 years). Tree age was estimated by means of the relationship between the tree's diameter at breast height (DBH, 14 m height) and its age, inferred from evidence based on ambitus studies in Wuhan (Xiao et al. 2020).

Class I protected plants have important ecosystem functions with relatively few individuals in narrow distribution. These plants receive the highest level of

Table 2 – Endangered animal species in the Daqi Mountain Nature Reserve.

No	Scientific name	Animal group	Endangered status
1	<i>Rana rugulosa</i>	Amphibian	II
2	<i>Chinemys reevesii</i>	Reptile	II
3	<i>Syrnaticus reevesii</i>	Bird	I
4	<i>Emberiza aureola</i>	Bird	I
5	<i>Accipiter nisus</i>	Bird	II
6	<i>Accipiter virgatus</i>	Bird	II
7	<i>Buteo buteo</i>	Bird	II
8	<i>Circus cyaneus</i>	Bird	II
9	<i>Circus melanoleucos</i>	Bird	II
10	<i>Circus spilonotus</i>	Bird	II
11	<i>Milvus migrans</i>	Bird	II
12	<i>Falco columbarius</i>	Bird	II
13	<i>Falco peregrinus</i>	Bird	II
14	<i>Falco subbuteo</i>	Bird	II
15	<i>Falco tinnunculus</i>	Bird	II
16	<i>Falco vespertinus</i>	Bird	II
17	<i>Pucrasia macrolopha</i>	Bird	II
18	<i>Tragopan temminckii</i>	Bird	II
19	<i>Tyto capensis</i>	Bird	II
20	<i>Asio flammeus</i>	Bird	II
21	<i>Asio otus</i>	Bird	II
22	<i>Glaucidium cuculoides</i>	Bird	II
23	<i>Strix aluco</i>	Bird	II
24	<i>Alauda arvensis</i>	Bird	II
25	<i>Garrulax canorus</i>	Bird	II
26	<i>Garrulax elliotii</i>	Bird	II
27	<i>Garrulax ocellatus</i>	Bird	II
28	<i>Luscinia calliope</i>	Bird	II
29	<i>Leiothrix lutea</i>	Bird	II
30	<i>Rhinomyias brunneata</i>	Bird	II
31	<i>Cuon alpinus</i>	Mammal	I
32	<i>Manis pentadactyla</i>	Mammal	I
33	<i>Martes flavigula</i>	Mammal	II
34	<i>Nyctereutes procyonoides</i>	Mammal	II
35	<i>Vulpes vulpes</i>	Mammal	II
36	<i>Prionailurus bengalensis</i>	Mammal	II
37	<i>Elaphodus cephalophus</i>	Mammal	II

protection in China. Class II protected plants have important ecosystem functions also, but are relatively less threatened than Class I protected plants. Class III protected plants require scientific management and rational utilization to ensure the stability of their populations.

Class I protected animals are very few in number and are usually very rare species, many of which are endangered or even nearly extinct in nature. The number of Class II protected animals is relatively high.

Threats

Global climate change

Global warming is recognized as one of the main threats to highland biodiversity (Fashing et al. 2022). Increased warming has changed the spatial distribution of many species within the flora and fauna in the highland regions (Xiong et al. 2023b). Climate warm-

ing has increased wildfire activity in many highland regions (Jones et al. 2022; Senande-Rivera et al. 2022). In interviews with local residents and protected area staff, they reported that there were over 70 wildfires in past 10 years in the DMNR. Although there has not been significant change in the frequency of wildfires, there has been a reduction of 185 hectares of forest cover due to wild fires between 2013 and 2020 (Fu et al. 2020). These wildfires seriously damaged local biodiversity and highland forest ecosystems. Meanwhile, extreme precipitation increased in Eastern Hubei Province, which is the region of the DMNR (Chen et al. 2018). During our field work we observed landslides covering endangered trees, such as *Ginkgo biloba*, *Huperzia serrata* and *Paris delavayi*, which changed ecosystem function and seriously stressed and threatened local biodiversity.

Human disturbance

Human disturbance poses an important threat to highland biodiversity (Yang et al. 2022). The human population increased to 1,542 in 2018, and the density of the human population on the DMNR reached 87 persons/km². Due to the remoteness of some villages within the area, more data are not available. By comparison the population density of the DMNR far exceeds that of other reserves in Hubei Province (20 person/km² in the Shennongjia National Nature Reserve, 26 person/km² in the Jiugong Mountain National Nature Reserve). Before 2002, forestry was the primary industry in the DMNR. A large quantity of forestry products, such as upon wood and seedlings, were gathered from this region and damaged the habitats for some endemic or endangered species. Traditionally, some residents hunted a great number of wild animals (such as *Vulpes vulpes*, *Arotonyx collaris*, *Sus scrofa* and *Muntiacus reevesi*) as food in Daqi Mountain and adjacent regions. And some species, such as *Manis pentadactyla* and *Chinemys reevesii*, have been captured for use in traditional Chinese medicine. As a result, the populations of some endemic or endangered species have declined sharply over the past 40 years (Xiang et al. 2006). Since the establishment of the DMNR hunting has been strictly prohibited. However, some local residents and tourists often collect mushrooms and inevitably destroy local vegetation, animal habitats and shelters. For example, several tons of mushrooms (mainly *Lactarius deliciosus*) have been harvested and removed from Daqi Mountain each year (according to communications with local residents). Now, many local residents depend on the development of tourism services (including the selling of mushrooms) for their survival.

Biological invasions

Biological invasions are one of the primary threats to global biodiversity, ecosystem function, human health and sustainable development (Simberloff et al. 2013). China has introduced a very high number of

non-native species that have become one of the most serious threats to its biodiversity (Xiong et al. 2015, 2017; Wang et al. 2016). The Yangtze River is one of the global invasion hotspots of non-native species and some habitats have experienced an exceptionally high invasion rate by non-indigenous species (Xiong et al. 2018, 2023a). Based upon our investigations, many non-native plant species (*Alternanthera philoxeroides*, *Bidens Pilosa*, *Erigeron bonariensis*, *Erigeron acris*, *Erigeron annuus* and *Solidago decurrens*) and animal species (*Rana rugulosa*, *Rana catesbeiana*, *Gambusia affinis*, *Procambarus clarkii* and *Achatina fulica*) have successfully established feral populations in the DMNR. As a result, some native endemic and endangered species, such as orchid species, amphibians and reptiles, have declined sharply due to competition, herbivory or predation by these non-indigenous species.

Measures for conservation

Long-term monitoring is a very important measure in biodiversity conservation (Ma 2011; Cavender-Bares et al. 2022). Some institutes, such as Huazhong Agricultural University, Hubei Ecology Polytechnic College, and the Hubei wild animal and plant protection station, have conducted field monitoring, pest control and plant identification and taxonomic classification in the DMNR over the past twenty years (Hu et al. 2007; Lei et al. 2013). However, none of these efforts have operated continuously for over five years. China is currently carrying out some large monitoring projects, such as those managed by CForBio (Chinese Forest Biodiversity Monitoring Networks) and NERNC (National Ecosystem Research Network of China), that include monitoring many important highland areas and habitats. New technologies, such as environmental DNA, UAV (unmanned aerial vehicle), remote sensing monitoring and artificial intelligence management, have been widely employed in ecological monitoring (Anderson & Gaston 2013; Willis 2015; Feng et al. 2022). These new technologies require more personnel training, new instrumentation and more funding dedicated to ecological monitoring. It is urgent that local governments better support monitoring resources, including overall funding, human resources and new technologies for long-term monitoring in the DMNR.

Fire is an important threat to biodiversity in some highland regions (Xiao et al. 2022). The DMNR is prone to forest fires. The terrain is high and steep and once a fire occurs, it is difficult to extinguish. Many residents living in the DMNR use field fires for agriculture, which can cause extensive forest fires if a fire escapes. The use of UAVs in monitoring wildfires has expanded the ability to control them (Ollero et al. 2006), and more UAV and professional training should be initiated in support of fire control in the DMNR.

Scientific research is an important protective measure for biodiversity because it provides ongoing and accurate data on many aspects of species habitats, the

condition of their populations and their viability over time (Purvis & Hector 2000). Recently, the populations of some endemic or endangered species (such as *C. japonicum*, *Z. schneideriana*, *P. delavayi* and *P. polyphylla*) have sharply decreased (Lei et al. 2012, 2013). More public awareness of and an emphasis on research regarding the propagation of non-native species through individual propagules, the management of both non-native and endangered species populations and habitat conservation for endangered species is needed. It is essential for local governments and environmental organizations better to support and fund ecological education and research in the DMNR.

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