Universität Bremen

Master Thesis

Investigation of endemic plants of calcareous scree slopes in Gesäuse National Park in Austria

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Acknowledgements

Above all, I would like to thank my first examiner, **Martin Diekmann**, who supported me when I had the idea of looking for a master's thesis topic in the Alps and who always took the time to answer all my questions.

I would also like to thank my second examiner, **Rainer Buchwald**, for taking the time to supervise me and my master's thesis.

A very special and big thanks goes to **Barbara Bock**, or as I much prefer to call her, Babsi, from the Gesäuse National Park, who responded to my request to write a master's thesis in the national park and suggested this wonderful and very exciting topic to me. I was always able to contact her at any time during my time in the Gesäuse and afterwards.

A big thank you goes to **Josef Müller**, who was kind enough to send me books on Alpine flora, which was a tremendous help for me in the field.

A warm thank you to **Cecilia Duprè**, who gave me so much helpful advice shortly before I travelled to Gesäuse and provided me with some nice tips for QGIS during the writing process.

I would also like to thank **Andreas Suchopar**, who always makes lab hours enjoyable and who took the time to examine the soil samples with me, which would have been quite a challenge without his help and extensive knowledge.

A sincere thank you to **Stefan Dietze** and **Doris Krause-Nicolai**, who took the time to proofread my work and gave me some useful tips for the final version.

Finally, I would like to thank my family and friends, who have always supported me during my work and made this intense period much easier for me. I am thinking in particular of my mother, **Irid Sündermann**, my sister, **Charlene Fritsch**, and my friends **Carlotta Marx**, **Svenja Krone** and **Leonie Eberts**.

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List of Abbreviations

AnI	Anthropogenic Impairment
DoP	Degree of Preservation
GLM	Generalized Linear Model
GLMM	Generalized Linear Mixed Model
GPS	Global Positioning System
H	indicates plant species that occurs in the herb layer
InN	Invasive Neophytes
MASL	Metres Above Sea Level
NB	Neighbouring Biotopes
NMDS	Nonmetric Multidimensional Scaling
Sh	indicates plant species that occurs in the shrub layer
ssp.	subspecies
T	indicates plant species that occurs in the tree layer

Abstract

Endemic species are essential for identifying biodiversity hotspots and conservation priorities. In the Eastern Northern Calcareous Alps – an important glacial refuge – calcareous scree slopes form a dynamic habitat that hosts highly specialised vegetation. However, detailed information on the distribution, environmental requirements and fitness of endemic vascular plants on these slopes is still limited.

This study examines four calcareous scree slopes in Gesäuse National Park – Haindlkar, Gseng, Langgries and Kühgraben. Vegetation surveys were conducted in 2×2 m plots arranged along transects, recording all vascular plant species and relevant environmental parameters. For endemic species, fitness traits were measured for all individuals found in the plots, and occurrences were additionally mapped via GPS. Species composition was analysed using NMDS ordinations, while GLMMs and GLMs were applied to assess the influence of environmental factors on endemic species abundance and fitness.

The vegetation on the scree slopes was shaped by multiple environmental drivers, most notably altitude, grain-size distribution, and total vegetation cover. Eleven endemic plant species were recorded, whose abundance was strongly related to altitude and the proportions of different debris fractions. Fitness patterns were primarily influenced by altitude, grain size and slope exposure.

Across the study area, three broad vegetation domains could be distinguished, structured mainly by grain size, substrate movement, altitude and radiation. The endemic species exhibited characteristic morphological and physiological adaptations that enabled them to occupy specific microhabitats within this extreme environment. Overall, the results provide novel insights into the fitness determinants and microhabitat preferences of endemic vascular plants on calcareous scree. The findings highlight that these species persist within narrow ecological niches and are highly specialised, emphasising their vulnerability and the importance of targeted conservation efforts.

1 Introduction

Biodiversity loss has become one of the most pressing challenges for humanity (Sánchez-Fernández *et al.*, 2025), with the global decline of species and ecosystems often described as the Earth's sixth mass extinction event (Cowie *et al.*, 2022). A recent and particularly striking example is the irreversible degradation of tropical coral reefs due to mass coral bleaching driven by global warming (Pearce-Kelly *et al.*, 2025; Zeng *et al.*, 2025).

On a global scale, 34 biodiversity hotspots have been designated as conservation priorities (Myers *et al.*, 2000; Mittermeier *et al.*, 2005). The exceptionally high richness of endemic species plays a central role in identifying these hotspots (Myers *et al.*, 2000), especially because ecosystems with high levels of endemism are often highly sensitive to global warming. Locally restricted endemics may be particularly vulnerable to global change, making the identification and prioritisation of species-rich and endemic-rich regions crucial for conservation planning (Malcolm *et al.*, 2006).

However, global hotspot designations alone are not sufficient for effective conservation. Their spatial resolution is too coarse, and therefore the identification of "hotspots within hotspots" (Cañadas *et al.*, 2014) is needed on regional and local scales. At such finer scales, endemic plant richness is a powerful tool for identifying priority areas (Noroozi *et al.*, 2019).

This also applies to the Alps, which represent a well-known hotspot of biodiversity and endemism. As an isolated mountain system, the Alps are predisposed to harbour a high number of endemic species (Silander, 2013). Within this broader region, more local centres of endemism have been identified, particularly in the Eastern Alps. The southern and eastern parts contain a large number of narrowly distributed endemic taxa, and these regions are considered glacial refuges (Tribsch, 2004). These refugia formed during the repeated glaciations of the past ~2.5 million years, during which the Alps were often extensively glaciated, while parts of the Eastern Northern Calcareous Alps remained ice-free. This unglaciated region – including the study area of this thesis – provided shelter for many organisms that survived unfavourable climatic periods, ultimately resulting in a pronounced "endemism hotspot".

In Austria, the province of Styria in particular has a high number of endemic species. There are 73 endemic vascular plants in this region, especially in the Ennstal Alps, which also include Gesäuse National Park (Rabitsch & Essl, 2008). Established in 2002, the national park covers 12,300 hectares and is protected under IUCN category II, meaning that habitats should remain undisturbed by activities such as forestry or gravel extraction, with alpine pastoralism being the only major exception (nationalparksaustria.at).

Among the ecologically remarkable habitats in the park are calcareous scree slopes, corresponding to the priority habitat type "Medio-European calcareous scree of hill and montane levels" (FFH-Lebensraumtyp 8160). These environments are shaped by intense physical weathering and gravitational processes, creating highly dynamic substrates (GIUPPONI, 2023). Furthermore, the edaphic conditions are not conducive to the formation of forests; instead, shrubs are characteristic, with vegetation cover rarely exceeding 10%. Temperature extremes are characteristic, as the open substrate heats up strongly in summer and cools dramatically in winter with prolonged snow cover (ELLMAUER *et al.*, 2020; LARCHER *et al.*, 2010). Previous studies have shown that, in addition to the chemical and physical properties of the rock, the decisive factors for the colonisation of this habitat are above all the mobility and the fine-earth content of the scree (JENNY-LIPS, 1930).

Calcareous scree slopes are characterised by plant communities of the pioneer/early stages of primary plant succession (GIUPPONI, 2023). Thus, inhabiting species must have special morphological traits and great regenerative capacity, which particularly affect the water and nutrient uptake (JENNY-LIPS, 1930). They are generally light-demanding and adapted to low vegetation cover (ELLENBERG & LEUSCHNER, 2010). Further adaptations which are frequently mentioned for scree vegetation are rosette and cushion growth to cope for radiation and water loss, succulence of the leaves to save water inside the plant body, production of secondary metabolites like pigments in the leaves to protect the photosynthetic tissue from insolation and the development of white petals to reflect solar radiation (BILLINGS, 1974; FISHER, 1952).

In the habitat described, plants have been changing during evolutionary processes in a way, that they are now better adapted than previously. In order to withstand the harsh conditions, this also leads to better fitness in this habitat compared to other species for which these conditions would be detrimental (BRADSHAW, 1971). Abiotic influences such as drought and extreme temperatures have been evaluated to be one of the biggest constraints to plant growth and productivity in extreme habitats (THALMANN & SANTELIA, 2017). Adaptations as described before therefore lead to a better fitness on calcareous scree. Rosette plants, for example, have been shown to survive in Alpine conditions at temperatures ranging from -25 to 60 °C (LARCHER, 2010). Understanding how plants perform specifically on calcareous scree slopes, and which environmental drivers most strongly influence their fitness, is therefore of considerable interest.

Within Gesäuse National Park, several typical calcareous scree slopes occur. Previous investigations at the lower Gseng have shown that endemic species such as *Asperula neilreichii*, *Biscutella laevigata* ssp. *austriaca* and *Campanula cespitosa* constitute established components of the local scree vegetation (ZIMMERMANN, 2021). However, precise knowledge of which endemic vascular plants occur on montane calcareous scree slopes remains limited. Particularly lacking is a detailed understanding of how these endemics are distributed across scree slopes, which environmental factors structure their occurrences, and how these factors relate to fitness traits.

Moreover, although several plant communities from higher altitudes and their endemic species have been well described (e.g. GREIMLER, 1997; MERTZ, 2002), it remains unclear how environmental conditions shape the vegetation of montane scree slopes as a whole.

The current state of knowledge and the remaining gaps regarding calcareous scree slopes in the Northeastern Calcareous Alps – especially concerning endemic vascular plants – lead to the following research questions:

I. How is the overall vegetation of calcareous scree slopes influenced by the environmental factors in the habitat?
II. Where do endemic plant species occur on calcareous scree slopes in the investigated area and how are they affected by the present environmental conditions?
III. How do environmental parameters affect the fitness of endemic vascular plants?

2 Material and Methods

2.1 Study area

The study was conducted in 'Gesäuse National Park' in Austria that is located in the Steiermark in the Eastern Alps. In this area, the annual average temperature is around 8.1 °C and the annual average precipitation amounts to about 1275 mm (data from 01.01.2007 to 17.10.2025 recorded at the measuring station 506 'Weidendom'; wegenernet.org – Data Portal of the Wegener Center). The study area included four calcareous scree slopes, the Haindlkar, the Gseng, the Langgries and the Kühgraben (Figure 1). All scree slopes are semi-active, characterised by large volumes of descending debris, especially during snowmelt. In many cases, material within these slopes is also transported by fluvial processes. During seasons of heavy rainfall, several temporary watercourses form on each slope, channelling water down the mountain and further enhancing material movement (ELLMAUER *et al.*, 2020).

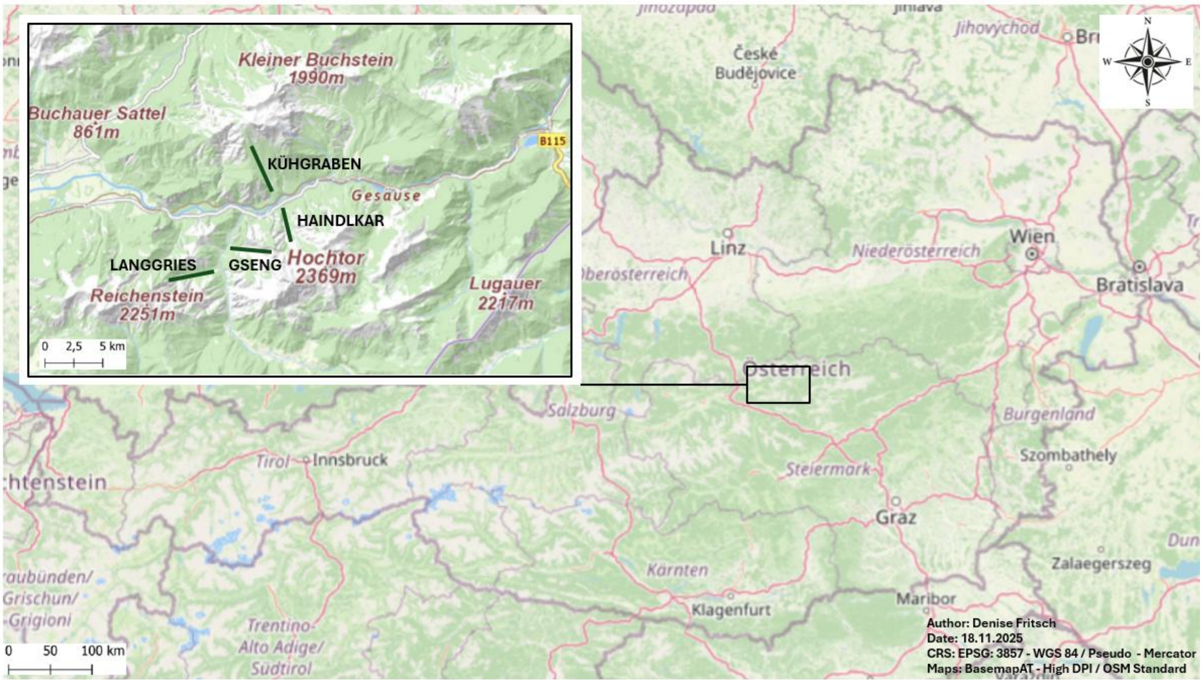

Figure 1 *Map showing the study area and where it is located in Austria. Green lines on the smaller map indicate where the scree slopes are located in the Gesäuse. For detailed maps of each slope compare Figures 2 and 3. Map was created using QGIS version 3.34.12.*

The Haindlkar originates on the northern side of the Hochtor Group, from where it descends the mountain in the same direction and extends over a height of approximately 500 metres (Figure 2). Its source rock is Wetterstein Dolomite, and in the upper section there is a ground moraine from the local glaciers. The Gseng also originates on the northern side of the Hochtor group but leads down to the western side of the mountain (Figure 2). It also covers an altitude of around 500 metres and has Wetterstein Dolomite as its source rock (maps.geosphere.at). In addition, there used to be an asphalt plant in the lower part of the Gseng, for which rubble was excavated mainly in the lower part of the trench, but also in higher parts. In 2008, the asphalt plant was closed, and rubble excavation was stopped. Since then, the natural dynamics of this trench have been restored and a spring located in the lower part also returned to its natural state (REMSCHAK, 2022). The Langgries originates at the summit of the Reichenstein and stretches down towards the east (Figure 3). It extends over approximately 400 metres in altitude, and its source rock is also Wetterstein Dolomite. The Kühgraben valley originates at the summit of the Großer Buchstein and descends southwards, covering a difference in altitude of around 1,000 metres (Figure 2). Its bedrock is composed of the surrounding rocks, consisting of Dachstein Limestone, Dachstein Dolomite and Wetterstein Dolomite. In the middle section, there is also a ground moraine from the local glaciers (maps.geosphere.at).

2.2 Vegetation survey and recording of environmental parameters

The vegetation surveys were conducted using the same method in all four calcareous scree slopes in July 2025. The vegetation was recorded in 2×2 m plots arranged in transects across each slope based on previous studies by Zimmermann in the Gseng (ZIMMERMANN, 2021). The distance between the plots of one transect was 5 m and between the different transects 50 m. The transects were set up from the lowest accessible point and extended to the highest reachable end of each scree slope. The Langgries was an exception here. The transects were started further up the scree slope and ended before reaching the highest point, as the debris in these areas was too loose and therefore no vegetation was present. This resulted in 26 transects on the Haindlkar, 17 on the Gseng, 18 on the Langgries, and 24 transects on the Kühgraben. Photos of all slopes can be found in the appendix (Figures A.1-A.4). The number of plots on the slopes varied, as each slope has a different width. In addition to the transects, plots were established at the edges of the slope on the Gseng and at the upper end of the slope on the Langgries, because typical scree vegetation was present here too. All in all, 140 plots were recorded on the Haindlkar, 113 on the Gseng, 191 on the Langgries and 75 on the Kühgraben, in total 519 plots. (Figures 2 and 3). The vegetation data was recorded using the Braun-Blanquet method (BRAUN-BLANQUET, 1964). Only vascular plants were considered, excluding mosses and lichens. Plant species were identified using field guides, among them were "Flora Alpina" volumes 1-3 (AESCHIMANN *et al.*, 2004) and "Exkursionsflora für Österreich, Liechtenstein und Südtirol" (FISCHER *et al.*, 2008). In addition to the species composition, the GPS location of each plot was recorded as well as several environmental parameters, including the total coverage of the vegetation, altitude in metres above sea level (MASL), exposure of the slope, radiation, estimated average slope inclination and the proportion of the grain size distribution (Table 1).

Table 1 Description of the scale used for recording the vegetation and measured environmental parameters and their classifications. These parameters were recorded for each plot on each scree slope.

Variable	**Description**
Plant coverage	Cover and abundance of vascular plant species: r rare: 1-3 individuals in plot + sparse: 4-10 individuals in plot 1 abundant: >10 individuals in plot or covering 1-5% of the plot 2m very abundant, but covering <5% of the plot 2a covering 5 to 12.5% of the plot 2b covering 12.5 to 25% of the plot 3 covering 25 to 50% of the plot 4 covering 50 to 75% of the plot 5 covering 75 to 100% of the plot
MASL	Altitude in metres above sea level
Exposure	Indicates the direction in which the slope is facing (north, east, south, west)
Radiation	Estimated intensity of light availability in the plot: sunny: >90% of the plot is exposed to direct sunlight mostly sunny: 60 to 90% of the plot is exposed to direct sunlight half shady: 30 to 60% of the plot is exposed to direct sunlight shady: <30% of the plot is exposed to direct sunlight
Average slope inclination	Estimated slope of the plot: slight: slope of <5° moderate: slope of 5 to 10° steep: slope of >10°
Proportion of the grain sizes	Estimated distribution of grain sizes in percent divided into three classes: Fine debris: substrate of <5 cm Coarse debris: substrate of 5 to 40 cm Block debris: substrate of >40 cm

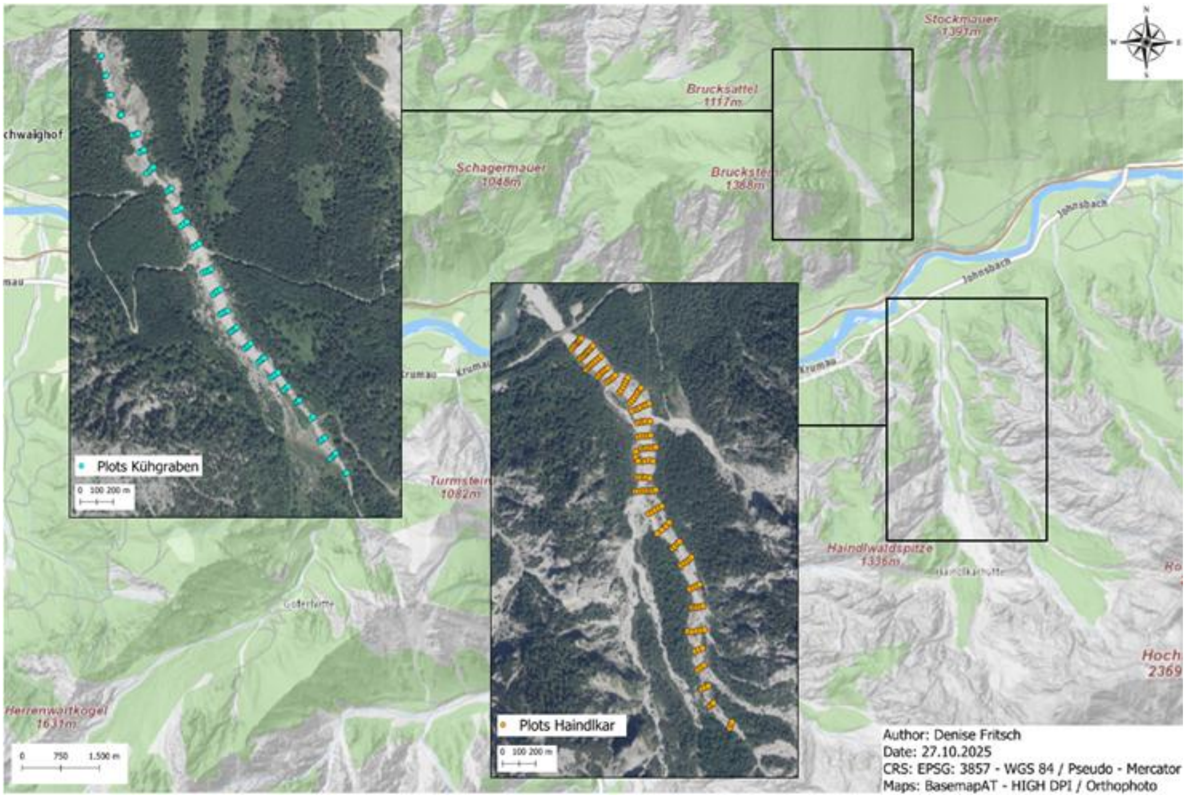

Figure 2 *Map showing the study area with inserted detailed maps of the Kühgraben and the Haindlkar. The blue dots show where plots for the vegetation survey were made on the Kühgrabem, orange dots for the Haindlkar. Maps were created using QGIS version 3.34.12.*

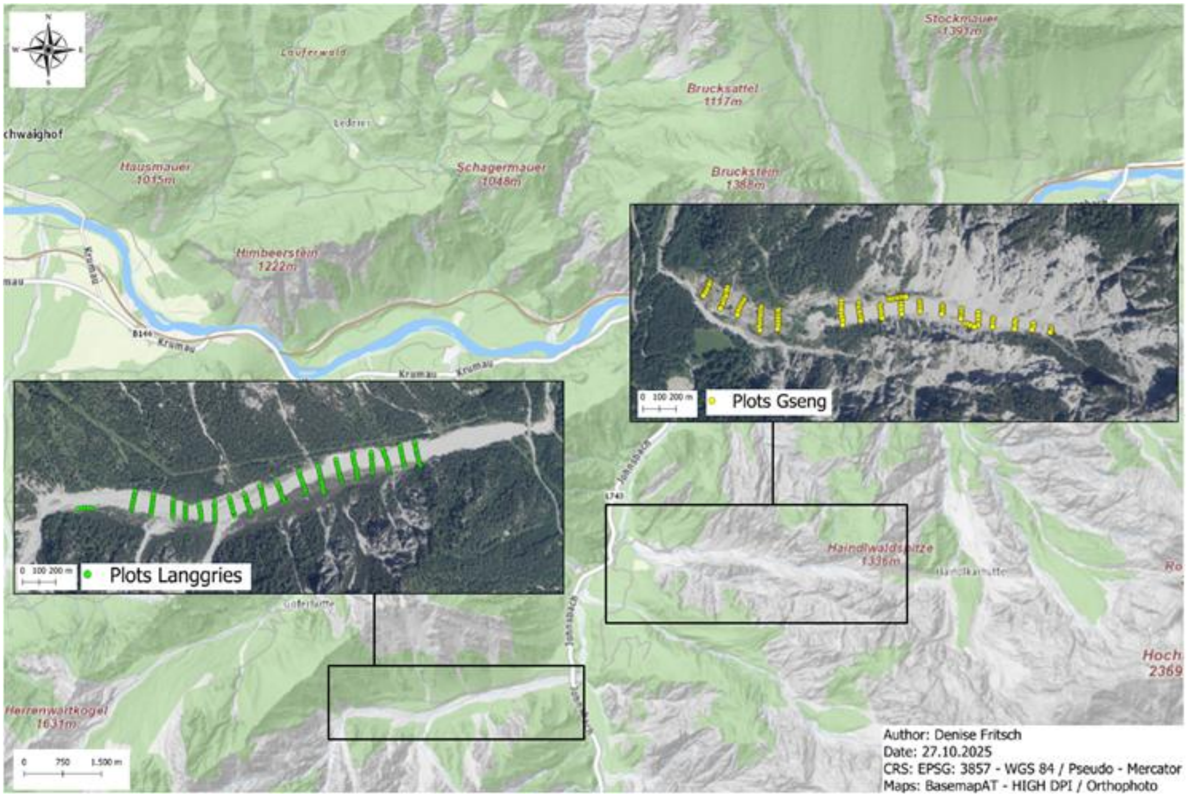

Figure 3 *Map showing the study area with inserted detailed maps of the Langgries and the Gseng. Green dots show where plots for the vegetation survey were made on the Langgries, yellow dots on the Gseng. Maps were created using QGIS version 3.34.12.*

2.3 Soil samples and laboratory analysis

Additionally, two EasyLog USB data loggers were installed on each scree slope – one in the lower part and one in the upper part – to collect data about the humidity and temperature variation in the slopes. Five samples of the surface layer of debris were also taken on each slope at suitable locations where debris vegetation and fine debris were present, in total 20 samples (Figure 4).

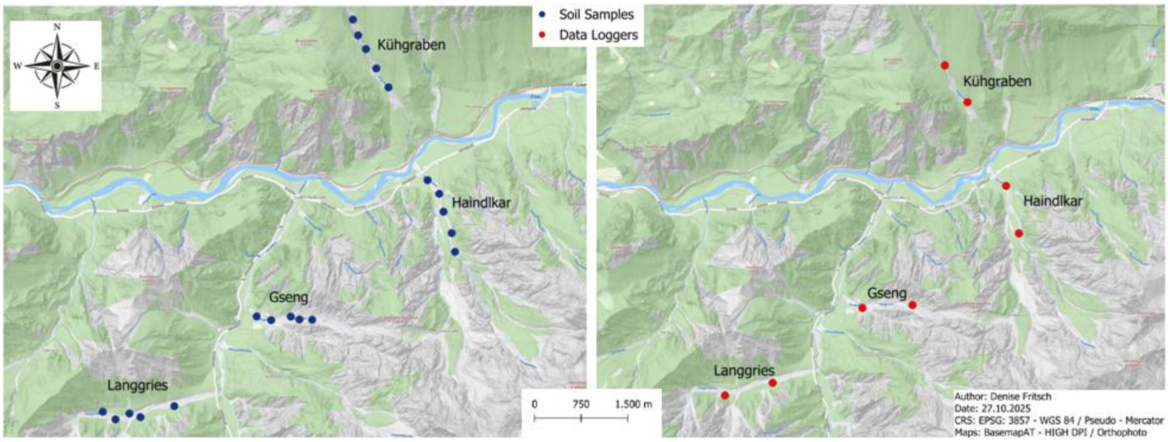

Figure 4 *Maps showing where soil samples were taken (on the left) and where the data loggers were set up for measuring (on the right). Maps were created using QGIS version 3.34.12.*

The pH was measured in the laboratory at University Bremen. Before measurement, the soil samples were dried and sieved through a 2 mm sieve. For the analysis of the pH, 10 g of the substrate was shaken with 25 ml of a 0.1 molar $CaCl_2$ solution in 100 ml PVC bottles. After one and a half hours, the pH was measured with a pH-electrode and a bench meter (SUCHOPAR 2024, unpublished).

2.4 Degree of preservation

As part of the monitoring of habitat types and species of importance, the Federal Environment Agency Austria created a qualitative assessment for high priority FFH- species and - habitat types. As the areas examined in this study belong to the habitat type 8160 (Medio-European calcareous scree of hill and montane levels), which is a high priority habitat type, they were classified according to the monitoring guidelines of the Austrian Federal Environment Agency. Thus, for each transect, calculations of the degree of preservation (DoP) were conducted with a qualitative assessment regarding influencing factors that affected the sites. The factors considered were effect of neighbouring biotopes (*NB*), anthropogenic impairment (*AnI*) and invasive and impairing species or neophytes (*InN*). A typical site is defined as a section that, according to the assessment, represents a homogeneous area within the protected territory that best exemplifies the degree of conservation (ELLMAUER *et al*., 2020). In this case one plot of each transect was chosen that represented the transect well. To this end, the influencing factors were divided into A, B and C, with A representing little to no influence, B denoting moderate influence and C meaning strong influence that significantly alters the habitat (Table 2).

Table 2 Explanations of the influencing factors documented for the qualitative assessment of the Austrian Federal Environment Agency. Each factor is classified as A, B or C according to the severity of its influence, with explanations given for the classification.

Indicator	**A**	**B**	**C**
		Influence	
Neighbouring biotopes (NB)	Environment largely unaffected (close to nature) or unchanged from its natural state (natural)	Slightly altered surrounding biotopes, but no significant adverse impact on the habitat	Surrounding biotopes significantly altered
Anthropogenic impairment (e.g. structural alterations, cuttings, thinning wood) (AnI)	No impairments apparent	Impairment (selective, affecting <10% of the area) present, but habitat and its dynamics hardly affected or not affected at all	Extensive impairment visible (on >10% of the area), which impairs habitat dynamics, if naturally formed
Invasive and impairing species or neophytes (InN)	Absent	Present in small numbers (covering 1 to 10%) but not affecting the habitat	Conspicuous (covering more than 10%) and adversely affecting or altering the habitat

2.5 Endemic plant species

An endemic plant is a species restricted to a specific geographic area, such as an island, lake, or otherwise limited region. The confinement of these species to narrow spatial ranges results from a combination of historical and ecological factors, which help explain both how a taxon became endemic and where its current distributional limits lie. Areas of endemism are defined as regions where the ranges of at least two endemic species overlap. Such areas can be used to establish hierarchical biogeographical classifications, meaning that smaller areas of endemism can be nested within larger ones (Fath, 2008). An example is the Ennstal Alps within the

Northern Calcareous Alps – an endemism hotspot situated in the Eastern Alps, where overall levels of endemism are already high.

Furthermore, especially isolated mountain ranges tend to have higher endemism per unit area due to topographically heterogeneous landscapes and therefore also variable climates and vegetation types. In such areas, plants evolved uniquely at a location and remained exclusive to that location. Therefore, these endemic plants had to develop several adaptations in order to survive in such heterogeneous and often harsh environments (SILANDER, 2013).

Prior to the actual vegetation assessment, an initial inspection of the scree slopes was conducted, during which a list of endemic species was compiled for detailed examination. As part of the vegetation survey, suitable fitness parameters were measured for each individual of the endemic plant species recorded in the plots. Depending on the botanical characteristics of each species, either leaf size or plant height was selected as the fitness parameter (Table 3). These measurements were taken only for the most common endemic species, as the remaining species were too rare – occurring in ten or fewer plots – to allow for meaningful statistical analysis. In addition, all endemic plant individuals observed during the vegetation surveys were point-mapped using GPS coordinates. After completing the vegetation surveys, all vegetated sections of the scree slopes were systematically searched for endemic species. When individuals occurred in clusters, they were recorded as a single GPS point, to which the respective number of individuals was assigned.

Table 3 List of all endemic plant species that was compiled after initial inspections of the scree slopes. For each species the family, characteristic adaptations as well as the measured fitness parameters are specified. Fitness parameters were only recorded for the species most frequently found in the plots (>10 plots across all scree slopes combined).

Species	**Family**	**Characteristic adaptations**	**Measured fitness parameter**
Asperula neilreichii	Rubiaceae	thin leaves and stem, white petals	-
Biscutella laevigata ssp. *austriaca*	Brassicaceae	rosette growth, thick leaves, long anchoring roots	Leaf size
Campanula cespitosa	Campanulaceae	thin leaves and stem, dense growth	-

Cerastium carinthiacum ssp. *carinthiacum*	Caryophyllaceae	thin leaves and stem, dense growth, white petals, long anchoring roots	Plant height
Dianthus plumarius ssp. *blandus*	Caryophyllaceae	cushion growth, short, hard leaves, long anchoring roots, short flowering period	-
Galium truniacum	Rubiaceae	thin leaves and stem, purple appearance/colour pigments, white petals, dense growth	Plant height
Heracleum autriacum ssp. *austriacum*	Apiaceae	white petals	-
Hieracium porrifolium	Asteraceae	thin leaves and stem, leaves additionally rolled up	Leaf size
Leucanthemum atratum	Asteraceae	thick leathery leaves, white petals	-
Papaver alpinum ssp. *alpinum*	Papaveraceae	thin stem and leaves, white petals	-
Primula clusiana	Primulaceae	rosette growth, thick succulent leaves, short flowering period	-

2.6 Data Analysis

All data analyses were carried out using the free statistical software R (version 4.3.3) and various packages specified below (R Core Team 2025). Prior to the analysis, the data was processed. For this purpose, the data was converted so that it could be entered into R Studio, i.e. for the vegetation data, the Braun-Blanquet scale was adjusted to range from 0 to 8 so that it had numerical values. For the environmental data, variables with classes were also converted into values for the same reason (Table 4).

Table 4 List of transformed variables for data analysis. The variables were converted from classes into numerical values for analysis purposes. For Radiation the class 'Shady' was excluded, as it was not categorised in the plots.

	Classes	**Numeric values**
Radiation	Sunny	1
	Mostly sunny	2
	Half shady	3
Average slope inclination	Slight	1
	Moderate	2
	Steep	3

2.6.1 Multivariate Analysis

For the multivariate analysis, plots without vegetation had to be excluded, as an ordination cannot process plots without vegetation. Of all 519 plots, vegetation was recorded on 324, so these could be used for the analysis.

To elaborate the vegetation differentiation of the scree slopes, a nonmetric multidimensional scaling (NMDS) ordination was carried out with a trymax of 100, which means that 100 various random initial configurations were tested to minimise the stress value. This increases the reliability of the NMDS solution. To further analyse how the environmental factors total coverage of the vegetation, altitude (MASL), exposure of the slope, radiation, average slope inclination and the proportion of the grain size distribution influenced the distribution of the vegetation, a fitting of environmental factors (envfit) with 2000 permutations was carried out. The NMDS and the environmental fitting were both performed using the package `vegan` (version 2.7-2, OKSANEN *et al.*, 2025). One NMDS analysis was carried out for each scree slope, resulting in four analyses. All of them were visualised in ordination plots, where the differences between points represent the differences in species composition. The influence of the environmental factors on the vegetation was represented by arrows, where longer arrows represented a stronger influence than shorter arrows.

2.6.2 Degree of preservation

To calculate the degree of preservation of each scree slope, the categorised plots that were determined to be representative for each transect were aggregated. The percentage of plots categorised as A, B and C was therefore calculated per scree slope. The results show the condition of the scree slopes in relation to the three factors considered. This provides an overview of how well preserved the habitats are and whether measures should be taken to better preserve the natural state of the scree slopes.

2.6.3 Analysis of endemic vascular plants

To evaluate if the environmental factors, including total coverage of the vegetation, altitude (MASL), radiation, inclination and the percentage share of block debris, coarse debris and fine debris, significantly influenced the abundance of endemic plant species, generalized linear mixed models (GLMMs) were used with exposure as a random factor. Exposure of the scree slopes was used as random factor, as the slopes descend into unique cardinal directions. For this purpose, data from all plots were used, as even plots without vegetation influence where species occur. This model was selected because it can represent the influence of the various environmental variables on the species, while also taking into account that the species occurred on four different scree slopes.

GLMMs were only performed for the most abundant endemic species – *Biscutella laevigata* spp. *austriaca*, *Cerastium carinthiacum* ssp. *carinthiacum*, *Galium truniacum* and *Hieracium porrifolium* – as all other endemics did not provide sufficient data to adequately explain such a model. Thus, four GLMMs were conducted, one for each of the endemic species mentioned. The distribution of each model was tested with a Pearson Chi-square test, the models then were run with a Poisson distribution using the packages `lme4` (version 1.1-37, Bates *et al.*, 2015) and `car` (version 3.1-3, Fox & Weisberg, 2019). To find the minimal adequate model, the GLMMs were reduced with stepwise reduction using a F-Test. Here, each of the four models was run, including all environmental parameters, endemic species as a fixed factor, and exposure as a random factor. All four models were then reduced until only significant ($p < 0.05$) variables were left.

To further analyse if the environmental factors significantly influenced the fitness of the endemic species, generalized linear models (GLMs) were run with leaf size or height of the plant as dependent variable and the environmental factors as independent variables. Here, only the data from the plots were used, in which endemic species were found and therefore fitness parameters could be recorded. In this case, exposure was also treated as an independent variable and not included as a random factor, as the data was insufficient to explain a GLMM resulting in singularity of the model. Here too, for the same reason, the GLMs were only performed for the four most common endemic species. To see if the data was dispersed normally the dispersion parameter was checked. If that was the case a Poisson distribution was used. In the case of underdispersed or overdispersed data, the models were run with a Quasi-Poisson distribution using the package `car` (version 3.1-3, FOX & WEISBERG, 2019). Again, the minimal adequate model was elaborated via stepwise reduction using a F-Test for each of the four GLMs. The analysis began with each full model, which was reduced until only significant ($p < 0.05$) variables and variables that best explained the models remained.

All figures illustrating the GLMMs and the GLMs were created using the package `ggplot2` (version 4.0.0, WICKHAM, 2016). For this, the predicted values calculated from the original data and the respective model were used, visualising the explaining and significant environmental factors of the final model.

3 Results

3.1 General results

In total, 154 plant species were found on all slopes combined, of which 111 species were present on the Haindlkar, 95 species on the Gseng, 93 species on the Langgries, and 84 species on the Kühgraben (Figures 5-8). The median total plant coverage was 5 % on the Haindlkar, 8 % on the Gseng, 7 % on the Langgries and 7 % as well on the Kühgraben. Of all plant species, 48 occurred on only one slope, 16 of which were on the Haindlkar, 20 on the Gseng and 6 each on the Langgries and the Kühgraben. Further, 45 plant species were found on all four slopes. A list of all plant species and the scree slopes on which they were identified can be found in the appendix (Table A.1).

The vast majority of species are categorised with Least Concern on Austria's Red List. However, a few species were found that are classified as being at risk. These include *Daphne cneorum*, *Galium pusillum* agg., *Leucanthemum vulgare* agg., *Saxifraga mutata*, *Scabiosa columbaria* ssp. *columbaria* and *Verbascum nigrum*, which are classified as Near Threatened, and *Cirsium* cf. *pannonicum* and *Epipactis palustre*, which are even classified as Vulnerable. In addition, two neophyte species were found. One of these is *Oenothera biennis*, a naturalised neophyte. The other one is *Erigeron annuus*, an invasive neophyte (SCHRATT-EHRENDORFER *et al*., 2022).

The most abundant species on the Haindlkar were *Salix eleagnos*, *Chlorocrepis staticifolia*, and *Calamagrostis varia*. In total, 24 additional species were found that occurred only once within a plot (Figure 5). On the Gseng, *Calamagrostis varia* and *Salix eleagnos* were also the most common species, followed by *Petasites paradoxus*. Here, 23 plant species were recorded that appeared only once in a plot (Figure 6). Similarly, on the Langgries, *Calamagrostis varia*, *Erica carnea*, and *Petasites paradoxus* were the most frequent species, while 19 species occurred only in a single plot (Figure 7). Finally, on the Kühgraben, *Calamagrostis varia*, *Petasites paradoxus*, and *Salix eleagnos* were again the most common species, with 22 species found only once within a plot (Figure 8).

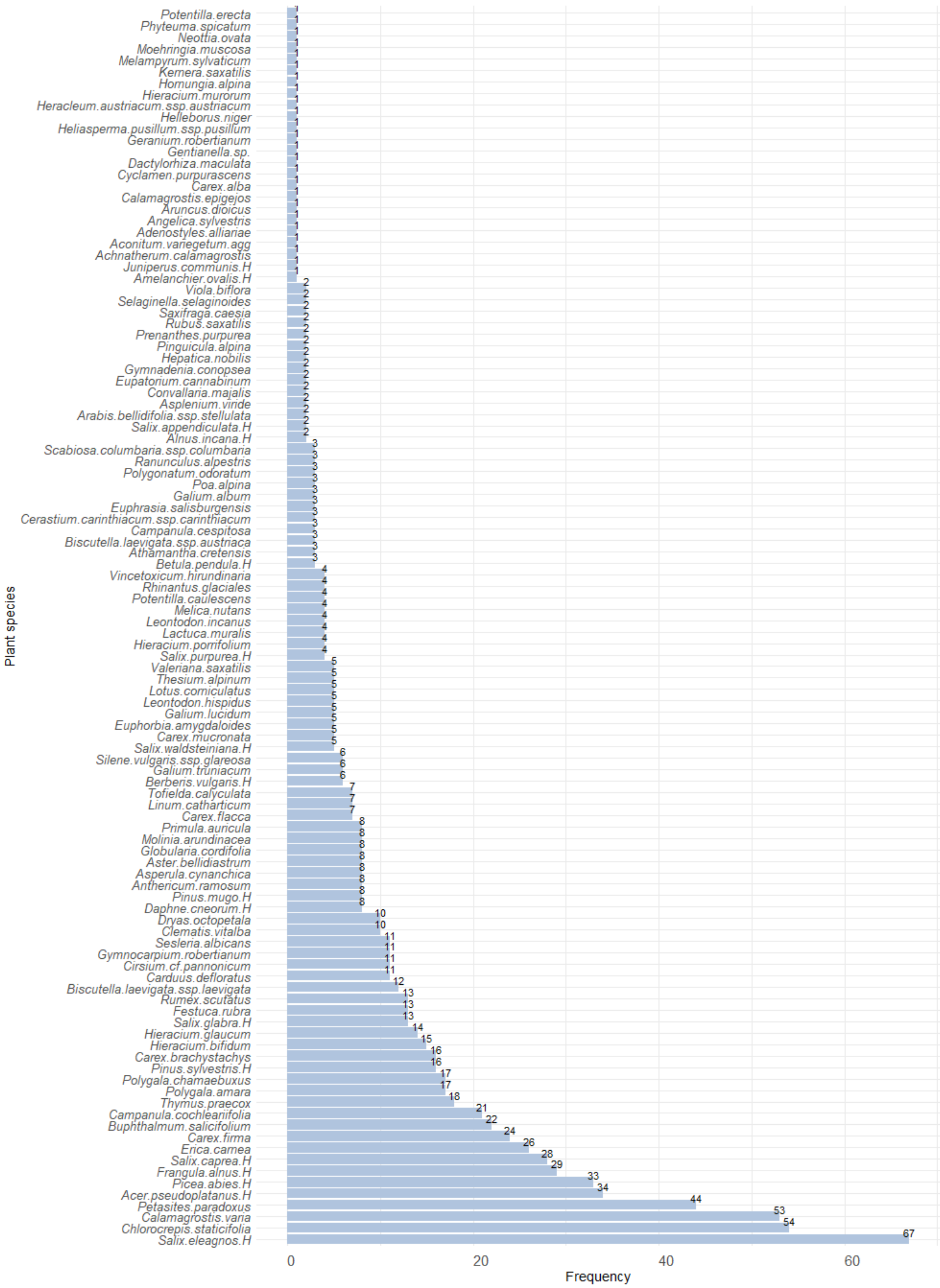

Figure 5 *Rank-frequency curve of the plant species found on the* ***Haindlkar****. Plant species are arranged in an increasing order of frequency from top to bottom. The frequency indicates in how many of all plots on this slope a species has occurred. A total of 140 plots were recorded on this scree slope.*

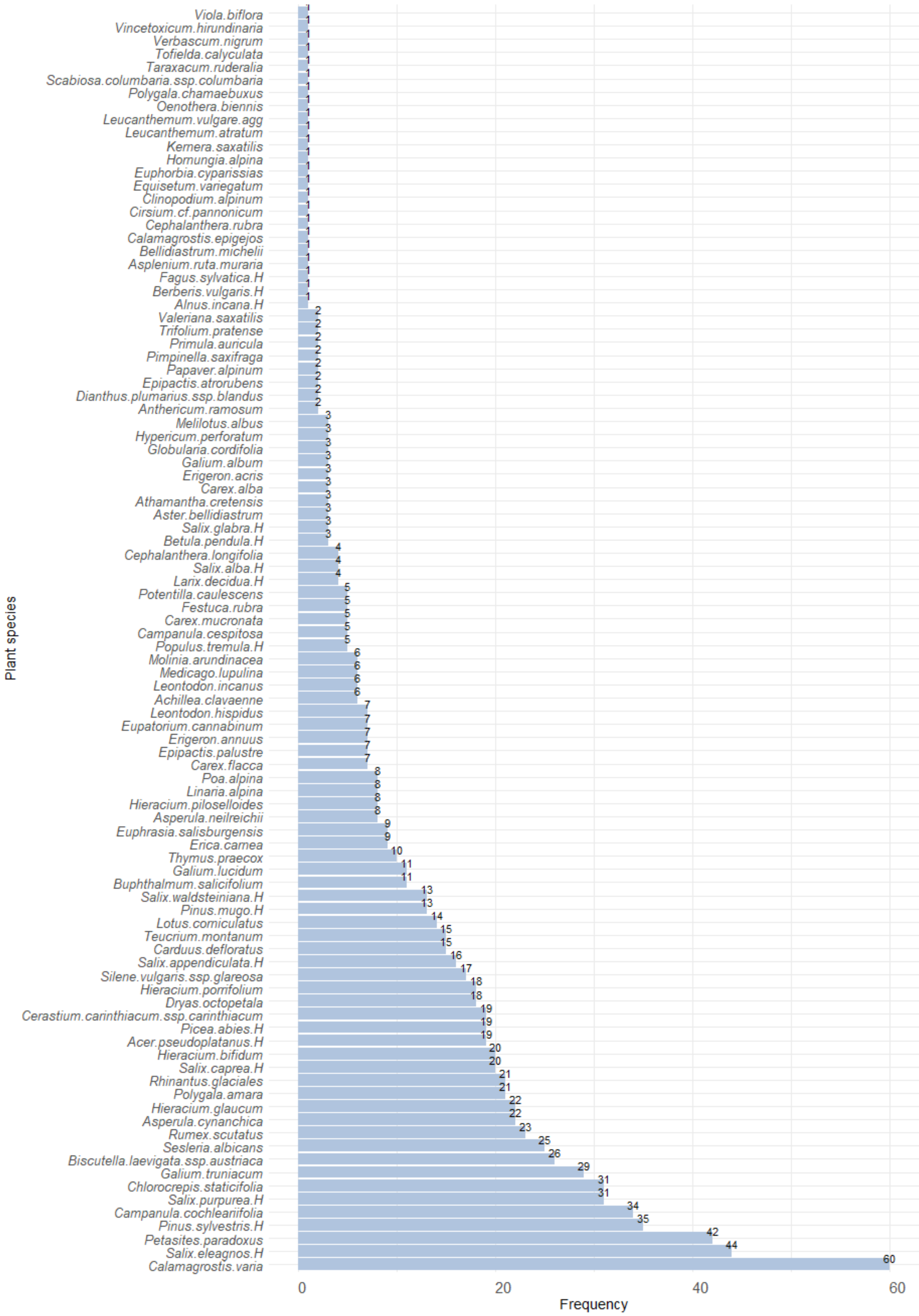

Figure 6 *Rank-frequency curve of the plant species found on the* ***Gseng****. Plant species are arranged in an increasing order of frequency from top to bottom. The frequency indicates how many of all plots of this slope a species has occurred. A total of 113 plots were recorded on this scree slope.*

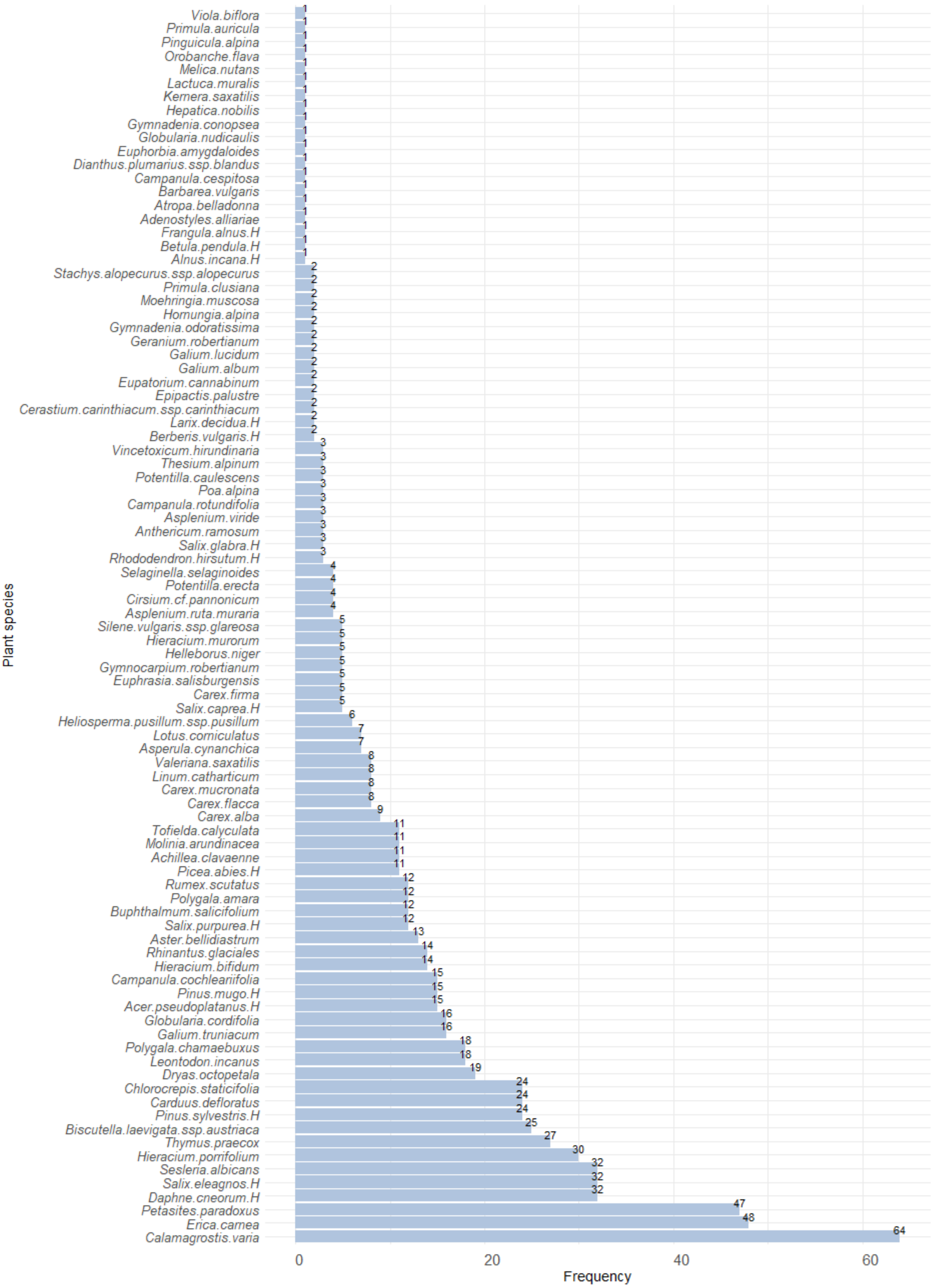

Figure 7 *Rank-frequency curve of the plant species found on the* ***Langgries****. Species are arranged in an increasing order of frequency from top to bottom. The frequency indicates how many of all plots of this slope a species has occurred. A total of 191 plots were recorded on this scree slope.*

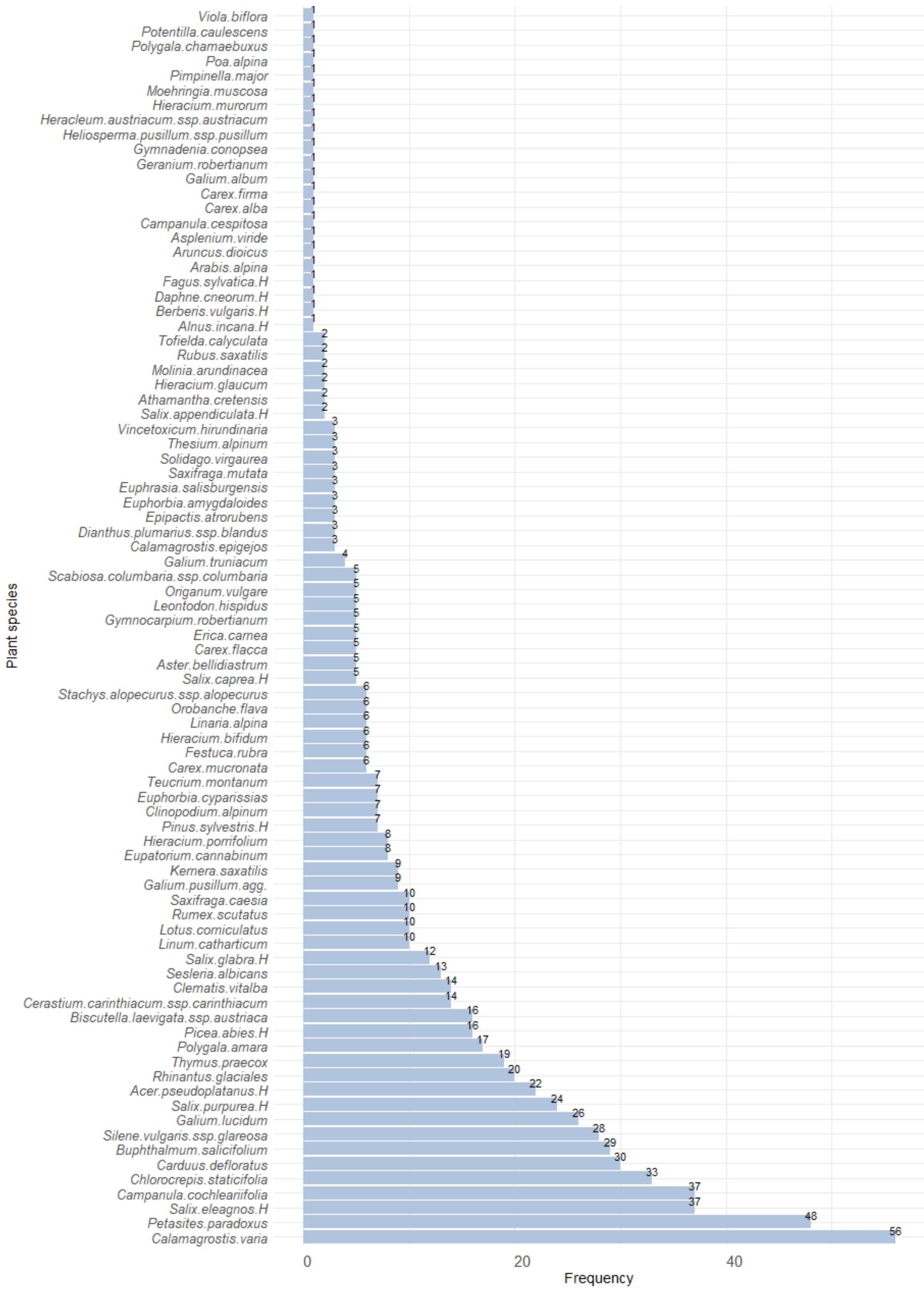

Figure 8 *Rank-frequency curve of the plant species found on the* ***Kühgraben****. Species are arranged in an increasing order of frequency from top to bottom. The frequency indicates how many of all plots of this slope a species has occurred. A total of 75 plots were recorded on this scree slope.*

3.2 Climate data

Data collection using data loggers has yielded several results. Data logger No. 76 failed to record measurements; therefore, no data are available for the upper part of the Langgries site. In general, a heatwave occurred at the beginning of July, accompanied by an absence of precipitation. Subsequently, temperatures dropped sharply, reaching daytime values of around 15 °C. Over the course of July, temperatures increased again several times but generally remained at moderate levels, with frequent rainfall during the rest of the month.

The highest temperature was recorded on the lower part of the Kühgraben, reaching 44.5 °C during the day. The lowest temperature, 7.5 °C at night, was also recorded at the Kühgraben, but in the higher elevated area. Overall, temperatures on the lower parts of the scree slopes were mostly higher than on the upper sections. The average humidity was higher at night than during daytime, whilst it generally remained higher in the lower sections of the scree slopes during both, daytime and nighttime (Figures 9 and 10, Table 4).

Temperature and humidity were strongly correlated; higher temperatures corresponded to lower humidity and vice versa. When temperatures reached 44.5 °C on the lower Kühgraben, relative humidity dropped to 20 % rH. As temperatures decreased to 10-20 °C during the day, humidity increased to 80-90 % rH, likely due to the onset of precipitation. This pattern was observed across all scree slopes, where nighttime humidity levels of 100 % were common. Even during the day, when temperatures increased again, humidity generally remained high (Figures 11 and 12, Table 5).

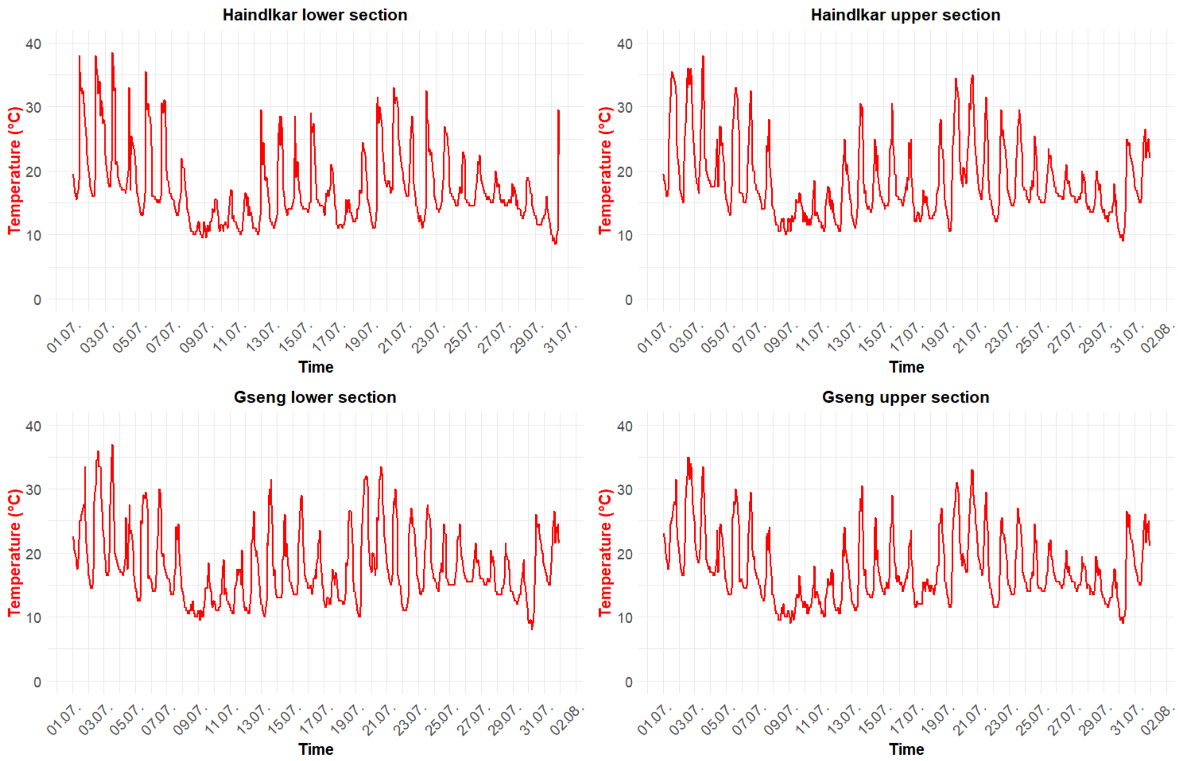

Figure 9 *Curves of the temperature (°C) measured with the data loggers that were installed on the Haindlkar and on the Gseng. The temperature was measured for the period of one month in July 2025.*

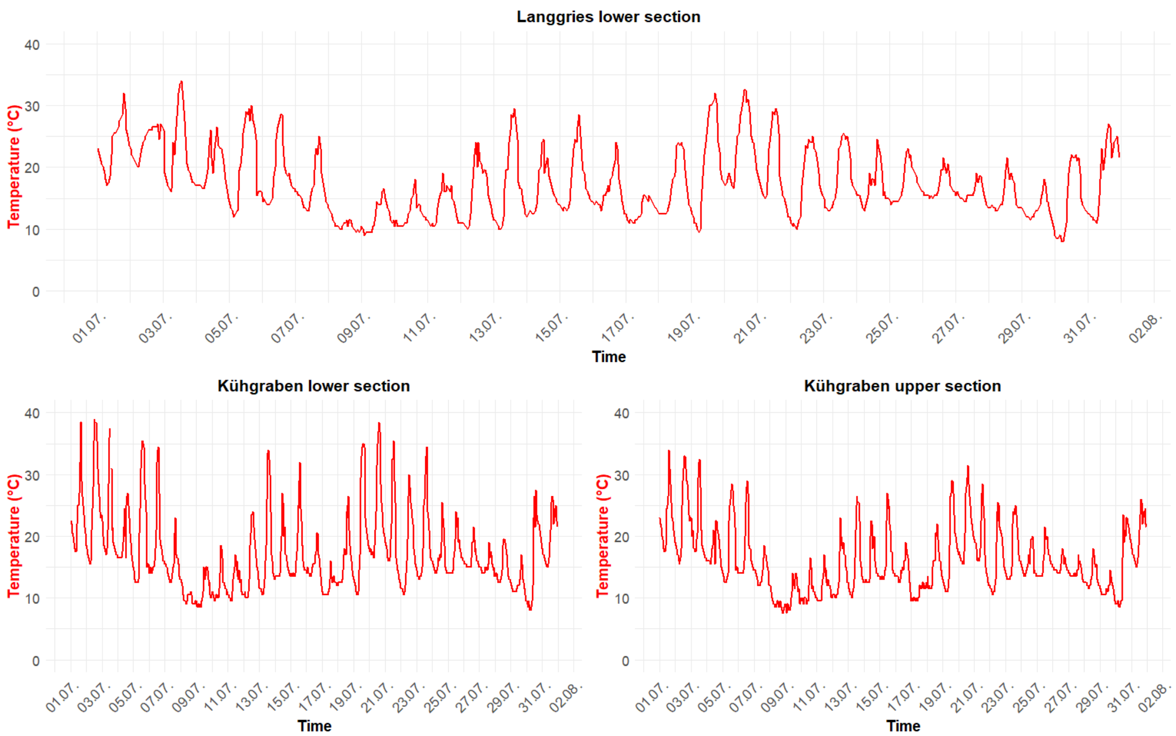

Figure 10 *Curves of the temperature (°C) measured with the data loggers that were installed on the Langgries and the Kühgraben. The temperature was measured for the period of one month in July 2025. The curve for the upper section of the Langgries is missing as the data logger failed to measure.*

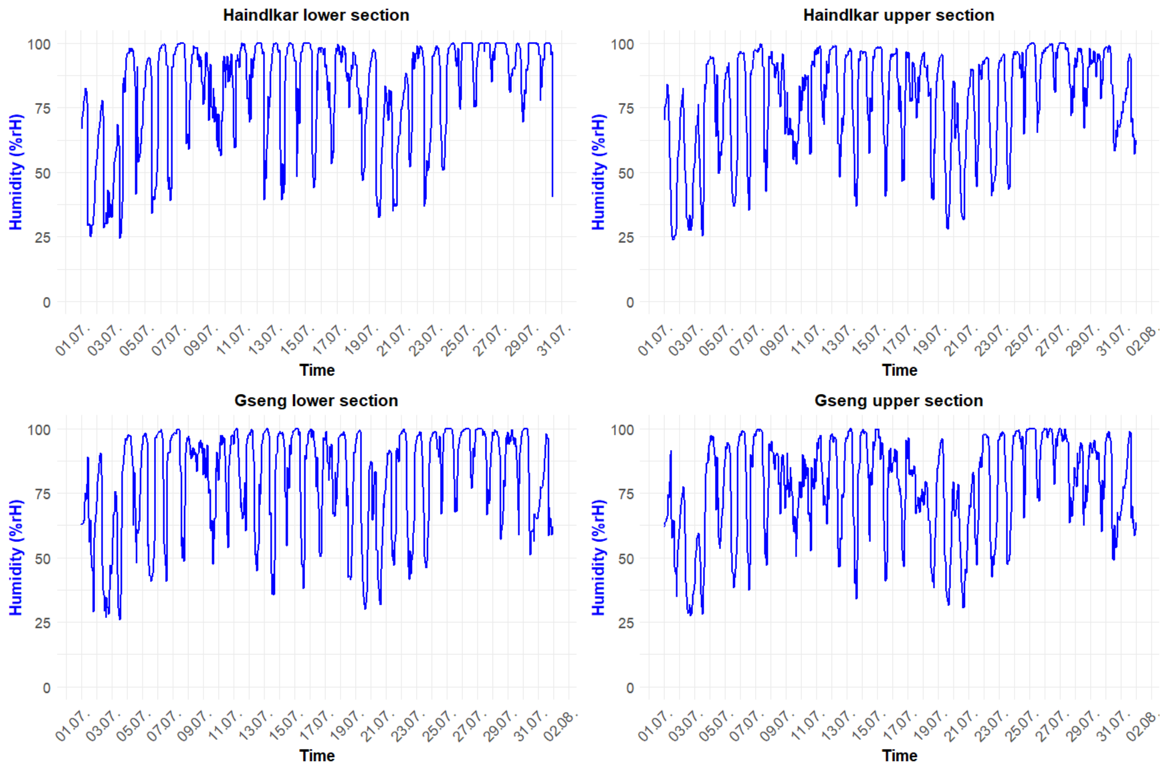

Figure 11 *Curves of the humidity (%rH) measured with the data loggers that were installed on the Haindlkar and on the Gseng. Humidity was measured for the period of one month in July 2025.*

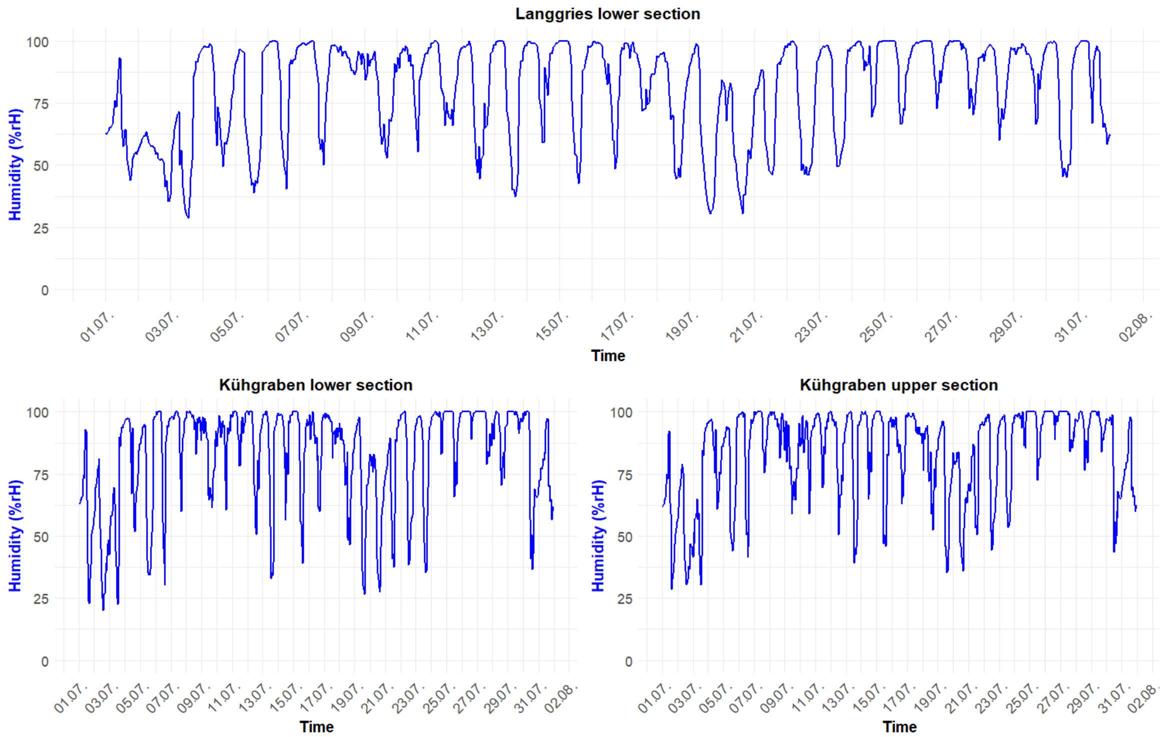

Figure 12 *Curves of the humidity (% rH) measured with the data loggers that were installed on the Langgries and on the Kühgraben. Humidity was measured for the period of one month in July 2025. The curve for the upper section of the Langgries is missing as the data logger failed to measure.*

Table 5 Average, lowest and highest temperature (°C) and humidity (% rH) of the recorded data from day and night on the scree slopes. Daytime hours extend from 6 a.m. to 9 p.m.; nighttime hours last from 9 p.m. to 6 a.m.

	Average Temp./ Humid., Day	**Min. Temp./ Humid., Day**	**Max. Temp./ Humid., Day**	**Average Temp. /Humid., Night**	**Min. Temp. /Humid., Night**	**Max. Temp. /Humid., Night**
Haindlkar bottom	19.0/75.5	8.5/24.5	38.5/100.0	14.4/91.4	8.5/32.5	28.0/100.0
Haindlkar top	20.1/72.5	9.0/24.0	38.0/100.0	15.1/89.0	9.0/43.0	26.5/100.0
Gseng bottom	19.7/73.4	8.5/26.0	37.0/100.0	14.6/91.4	8.0/37.5	26.5/100.0
Gseng top	19.0/72.0	9.0/27.5	35.0/100.0	14.9/86.5	9.0/33.5	27.5/100.0
Langgries bottom	19.3/73.8	8.0/28.5	34.0/100.0	14.3/91.6	8.0/35.5	27.0/100.0
Kühgraben bottom	19.2/77.2	8.0/20.0	44.5/100.0	14.1/91.2	8.0/42.5	25.0/100.0
Kühgraben top	17.3/79.2	7.5/28.5	34.0/100.0	13.7/90.3	7.5/41.5	24.5/100.0

3.3 Soil samples

The analysis of the soil samples of the four scree slopes has shown that the pH varies between 7 and 8, with no significant differences in pH between the various sites (Table 6).

Table 6 List of pH-values of the four different scree slopes. On each slope, five soil samples were collected. The pH was measured in the laboratory, for details compare method part 2.2 Vegetation survey and recording of environmental parameters.

	Haindlkar	**Gseng**	**Langgries**	**Kühgraben**
Sample 1	7.9	7.8	7.5	7.9
Sample 2	7.9	7.6	7.4	7.8
Sample 3	7.6	7.9	8.0	8.0
Sample 4	7.7	7.7	7.8	8.1
Sample 5	8.0	7.8	7.8	7.9

3.4 Multivariate analysis

3.4.1 Analysis of the Haindlkar

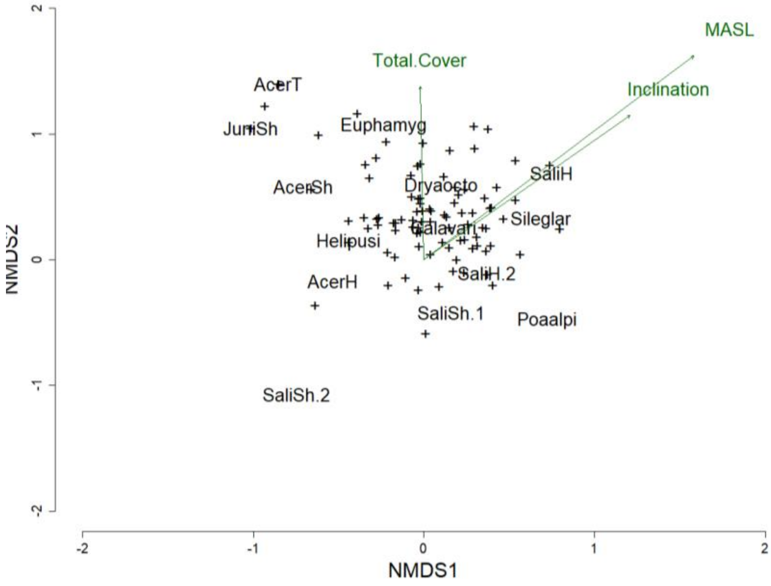

*Figure 13 Ordination diagram of the NMDS with species found on the **Haindlkar** and the environmental parameters Inclination and Elevation (MASL) shown as green vectors. The most frequent species are shown with shortnames, less frequent speces are indicated by black crosses.*

The NMDS analysis of the vegetation on the Haindlkar revealed that both average slope inclination and altitude (MASL) significantly influenced the vegetation. Additionally, total cover was significant which indicates a strong correlation of the distribution of the species to the vegetation cover ($p < 0.05$). Moreover, inclination and the altitude level (MASL) showed a strong positive correlation in their effect on the species composition. *Potentilla caulescens*, *Silene glareosa* ssp. *glareosa*, and *Carex mucronata* were clustered along the gradients of inclination and MASL, indicating that these species occurred more frequently in plots with steeper slopes and higher elevations. Species positioned near the centre of the ordination – such as *Betula pendula* H, *Salix caprea* H, and *Frangula alnus* – were not notably influenced by these two parameters. In contrast, species that were more common in plots with lower inclination and altitude levels were located opposite to these vectors. These included *Clematis vitalba*, *Salix purpurea* Sh, and *Petasites paradoxus*. Species that were grouped along the gradient of total cover and therefore occurred more frequently in plots with higher plant cover were *Dryas octopetala* and *Euphorbia amygdaloides* (Figure 13).

3.4.2 Analysis of the Gseng

The analysis of species composition on the Gseng revealed that MASL, average slope inclination, and grain size (classified as fine debris, coarse debris, and block debris) all had a significant influence on vegetation ($p < 0.05$). In this case, block debris and coarse debris were strongly correlated, as indicated by the small angle between their gradients. Inclination and altitude were also positively correlated with these variables. In contrast, total vegetation cover – which was also significant and thus showed a strong correlation with species composition – was positively correlated with fine debris, but these two variables correlated negatively with the other gradients.

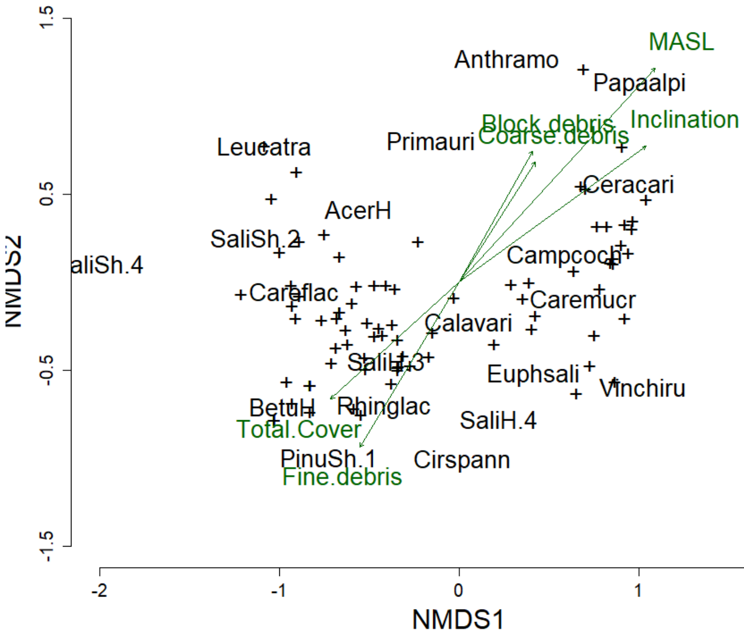

Figure 14 Ordination diagram of the NMDS with the species that were found on the ***Gseng****. Environmental parameters from the environmental fitting are Block debris, Coarse debris, MASL, Inclination, Total Cover and Fine debris. They are indicated by green vectors. Block debris and Coarse debris are overlapping as they are strongly correlated. The most frequent species are displayed as shortnames, less frequent species are indicated by black crosses.*

Species clustered along the gradients pointing in the direction of inclination included *Kernera saxatilis*, *Papaver alpinum* ssp. *alpinum*, and *Linaria alpina*. These species were more common in plots with steeper slopes, higher altitudes, and greater proportions of coarse and block debris. Conversely, species such as *Rhinanthus glacialis*, *Dryas octopetala*, and *Lotus corniculatus* were associated with the gradients of total cover and fine debris, occurring primarily in plots with higher vegetation cover and finer substrate. Species that were not notably influenced by any of the measured parameters and therefore positioned near the centre of the ordination plot, included *Calamagrostis varia*, accompanied by *Buphthalmum salicifolium* and *Leontodon incanus* (Figure 14).

3.4.3 Analysis of the Langgries

The analysis of vegetation on the Langgries revealed that radiation, fine debris, block debris, average slope inclination, and MASL significantly influenced species distribution. Again, the total plant cover also had a strong correlation to species composition ($p < 0.05$). In this case, radiation and fine debris were highly correlated, as indicated by the small angle between their gradients. Total vegetation cover was also positively correlated with these two variables. In contrast, block debris, inclination, and altitude were positively correlated with each other but negatively correlated with the first group of variables.

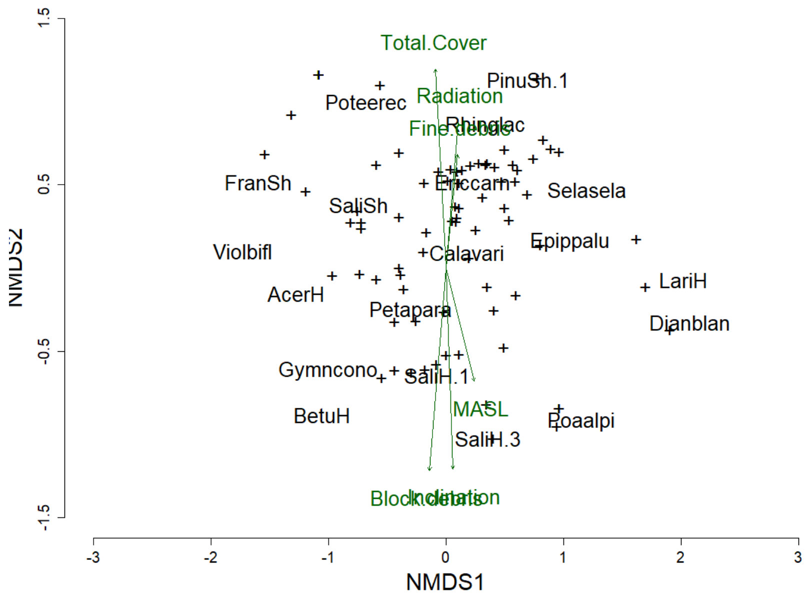

__Figure 15__ Ordination diagram of the NMDS with the species that were found on the __Langgries__ and environmental parameters shown as green vectors. The parameters from the environmental fitting are Total Cover, Radiation, Fine debris and elevation and Block debris and Inclination, where the nametags overlap as these variables were highly correlated. Frequent species are displayed as shortnames, less frequent species are indicated by black crosses.

Several species were clustered in the direction of the gradients on the positive side of the second NMDS axis, including *Thymus praecox*, *Dryas octopetala*, *Galium truniacum*, and *Rhinanthus glacialis*. These species occurred primarily in plots with higher vegetation cover, greater shading, and higher proportions of fine debris. Species clustered on the negative side of the second NMDS axis were more common in plots with greater proportions of block debris, steeper slopes, and higher altitudes. However, the MASL gradient was only about half as long as those of the other two parameters, indicating a comparatively weaker effect. Species associated with this direction included *Cerastium carinthiacum* ssp. *carinthiacum*, *Gymnocarpium robertianum*, and *Salix eleagnos* H. Species located approximately at a 90-degree angle to the environmental gradients in the ordination – and therefore being neutral to them – included *Dianthus plumarius* ssp. *blandus*, *Viola biflora*, and *Biscutella laevigata* ssp. *austriaca* (Figure 15).

3.4.4 Analysis of the Kühgraben

Finally, on the Kühgraben, the analysis showed that MASL, average slope inclination, fine debris, coarse debris and radiation influenced species distribution. Additionally, the total coverage was significant and therefore showed a strong correlation to the species composition ($p < 0.05$). Inclination, MASL, and fine debris were positively correlated, whereas coarse debris was negatively correlated with this group. Radiation and total vegetation cover were strongly correlated with each other but largely independent of the other environmental variables.

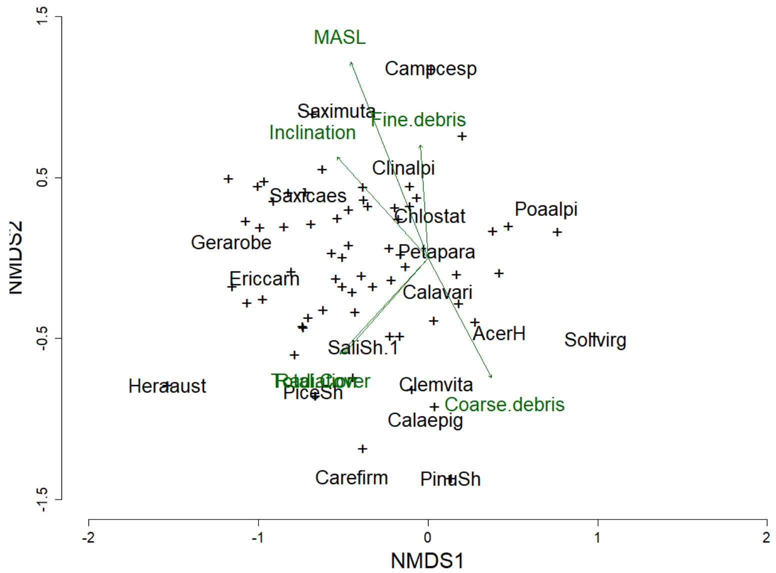

Figure 16 *Ordination diagram of the NMDS with the plant species that were found on the Kühgraben with environmental parameters shown as green vectors. The environmental fitting included the variables elevation, Inclination, Fine debris and Coarse debris and Total Cover and Radiation, where the nametags overlap as these variables are highly correlated. Frequent species are displayed with shortnames, less frequent species are indicated by black crosses.*

Species clustered along the gradients in the direction of altitude included *Saxifraga caesia*, *S. mutata*, *Clinopodium alpinum*, and *Dianthus plumarius* ssp. *blandus*. These species occurred more frequently in plots with higher inclination, higher altitude, and greater proportions of fine debris. In contrast, species located along the gradient of coarse debris – such as *Acer pseudoplatanus* H and *Galium album* – were more common in plots with higher proportions of coarse material. Additionally, some species were not influenced by the previously mentioned parameters but were instead associated with total vegetation cover and radiation. These included *Rubus saxatilis*, *Epipactis atrorubens*, and *Euphorbia amygdaloides*, which occurred more often in plots characterised by denser vegetation and greater shading (Figure 16).

3.4.5 Summarised findings of the multivariate analysis

In summary, several patterns were consistent across all four scree slopes. Whenever both total vegetation cover and radiation were significant, they were always positively correlated with each other. Similarly, average slope inclination and MASL, when both significant, also showed a positive correlation. The relationships among debris size classes were either strongly positive or negative. Specifically, the proportions of coarse debris and block debris, when both significant, were highly positively correlated, whereas fine debris consistently showed a negative correlation with one or both of the larger grain-size fractions.

In terms of vegetation, species such as *Calamagrostis varia* and *Petasites paradoxus* – both common across all sites – were consistently positioned near the centre of the ordination diagrams, indicating that they were largely unaffected by the environmental parameters measured. In contrast, rarer species tended to cluster along the gradients of the environmental variables, suggesting that their distribution was more strongly influenced by these factors.

3.5 Degree of preservation

The calculation of the degree of preservation (DoP) yielded varying results across the four scree slopes. On the Haindlkar, no transect was categorised as C for any indicator. For the indicator invasive neophytes (*InN*), all transects were classified as A, as no invasive neophytes were recorded. The indicators neighbouring biotopes (*NB*) and anthropogenic influence (*AnI*) showed slightly lower scores, with 4% of the area categorised as B for *NB* and 8% as B for *AnI*. Nevertheless, these results indicate that most of the area remains in a near-natural condition.

At the Gseng site, 100% of the area was classified as A for *NB*, meaning that all adjacent biotopes were in good condition. In contrast, *AnI* revealed human alterations in 29% of the area, which was categorised as B. The *InN* indicator showed a similar trend, with 24% of the area categorised as B, showing a higher appearance of invasive species. These B classifications were concentrated mainly in the valley, while more than two-thirds of the area remained in category A.

The Langgries site showed the clearest results, with 100% of the area classified as A for all three indicators. This shows that this slope is in the best condition with respect to its naturalness.

For the Kühgraben, the *NB* indicator also showed excellent results, with 100% of the area classified as A. The same pattern was observed for *InN*, as no invasive species were found. However, the results for *AnI* were less favourable. In the higher areas of this slope, moderate to strong anthropogenic alterations were recorded. Here, 50% of the slope was categorised as B, 4% as C, and only 46% as A. Photographs illustrating the anthropogenic influence on this slope, along with the percentage classifications for each scree slope, are provided in the appendix (Figure A.1-A.4; Table A.4).

Overall, the DoP indicates that most slopes are in very good condition regarding their naturalness. However, the results also highlight areas where improvement is needed. This is particularly evident at the lower part of the Gseng, where invasive neophytes appear to be spreading, and at the Kühgraben, where anthropogenic disturbances restrict the natural dynamics of the slope.

3.6 Endemic plant species

3.6.1 Number of endemic vascular plants and distribution on the scree slopes

In total, eleven endemic plant species were recorded across all four scree slopes. Of these, nine occurred on the Gseng. This was also the slope with the highest number of endemic species as well as three endemic species which were exclusively found here. On each of the other slopes, the Haindlkar, Langgries, and Kühgraben, seven endemic species were found in various combinations which can be seen in Table 7. The endemic species identified were *Biscutella laevigata* ssp. *austriaca*, *Dianthus plumarius* ssp. *blandus*, *Galium truniacum*, *Heracleum austriacum* ssp. *austriacum*, *Leucanthemum atratum*, *Papaver alpinum* ssp. *alpinum*, and *Primula clusiana*, which are endemic to Austria, as well as *Asperula neilreichii*, *Campanula cespitosa*, *Cerastium carinthiacum* ssp. *carinthiacum*, and *Hieracium porrifolium*, which are endemic to the Eastern Alps (Figures 17 and 18). The most common endemic vascular plants were *Biscutella laevigata* ssp. *austriaca*, *Cerastium carinthiacum* ssp. *carinthiacum*, *Galium truniacum* and *Hiaracium porrifolium*. All observed endemic species occurred on the scree slopes, either in similar locations or in different microhabitats. This is possible due to various adaptations of the species to the habitat, which were mentioned in section 2.5 and are documented in Figure 19.

The distribution of endemic plant species was mainly concentrated at the edges of the scree slopes. Nevertheless, in some cases endemics were also found in the middle of the areas. On the Haindlkar, hotspots of endemic species were found at medium altitudes, which was also the case on the Kühgraben. On the Gseng, endemic species were mainly found in the upper half of the slope, while on the Langgries they were distributed more or less evenly across the scree slope (Figure 20). Detailed maps of the distribution of each endemic plant species can be found in the appendix (Figures A.5-A.8).

Table 7 List of all endemic plant species which have been identified in the research area. Listed are the counts in how many of all plots on the scree slopes they were found. For *Primula clusiana* the count is zero on the Haindlkar as this species was not recorded in the plots but was found during the point mapping of the endemic plants. Species which are marked in green were only found on one slope; species which are marked in yellow were found on all slopes.

	Haindlkar	Gseng	Langgries	Kühgraben
Asperula neilreichii	-	8	-	-
Biscutella laevigata ssp. *austriaca*	13	26	25	16
Campanula cespitosa	3	5	1	1
Cerastium carinthiacum ssp. *carinthiacum*	3	19	2	14
Dianthus plumarius ssp. *blandus*	-	2	1	3
Galium truniacum	6	29	16	4
Heracleum austriacum ssp. *austriacum*	1	-	-	1
Hieracium porrifolium	4	18	30	8
Leucanthemum atratum	-	1	-	-
Papaver alpinum ssp. *alpinum*	-	2	-	-
Primula clusiana	0	-	2	-

Figure 17 *Photos of the endemic plant species that were found in the research area from top left to bottom right:* Asperula neilreichii*, leaves, fruits and flowers of* Biscutella laevigata *ssp.* austriaca*,* Cerastium carinthiacum *ssp.* carinthiacum*, cushion-like stand and fruit stand from* Dianthus plumarius *ssp.* blandus *and vegetative stand of* Campanula cespitosa *without flowers as flowering period of that species was later than time of research.*
© Denise Fritsch

Figure 18 *Photos of the endemic plant species that were found in the research area from top left to bottom right: leaves and flowers of* Galium truniacum*, flower stand and leaves of* Heracleum austriacum *ssp.* austriacum*, flowers and leaves of* Hieracium porrifolium*,* Papaver alpinum *ssp.* alpinum *and leaves of* Primula clusiana *without flowers as flowering season of that species was already over. © Denise Fritsch*

Figure 19 *Photos of long anchoring roots as an adaptation to the environment exhibited by* Biscutella laevigata *ssp.* austriaca *(left),* Dianthus plumarius *ssp.* blandus *(middle) and* Cerastium carinthiacum *ssp.* carinthiacum *(right). © Denise Fritsch*

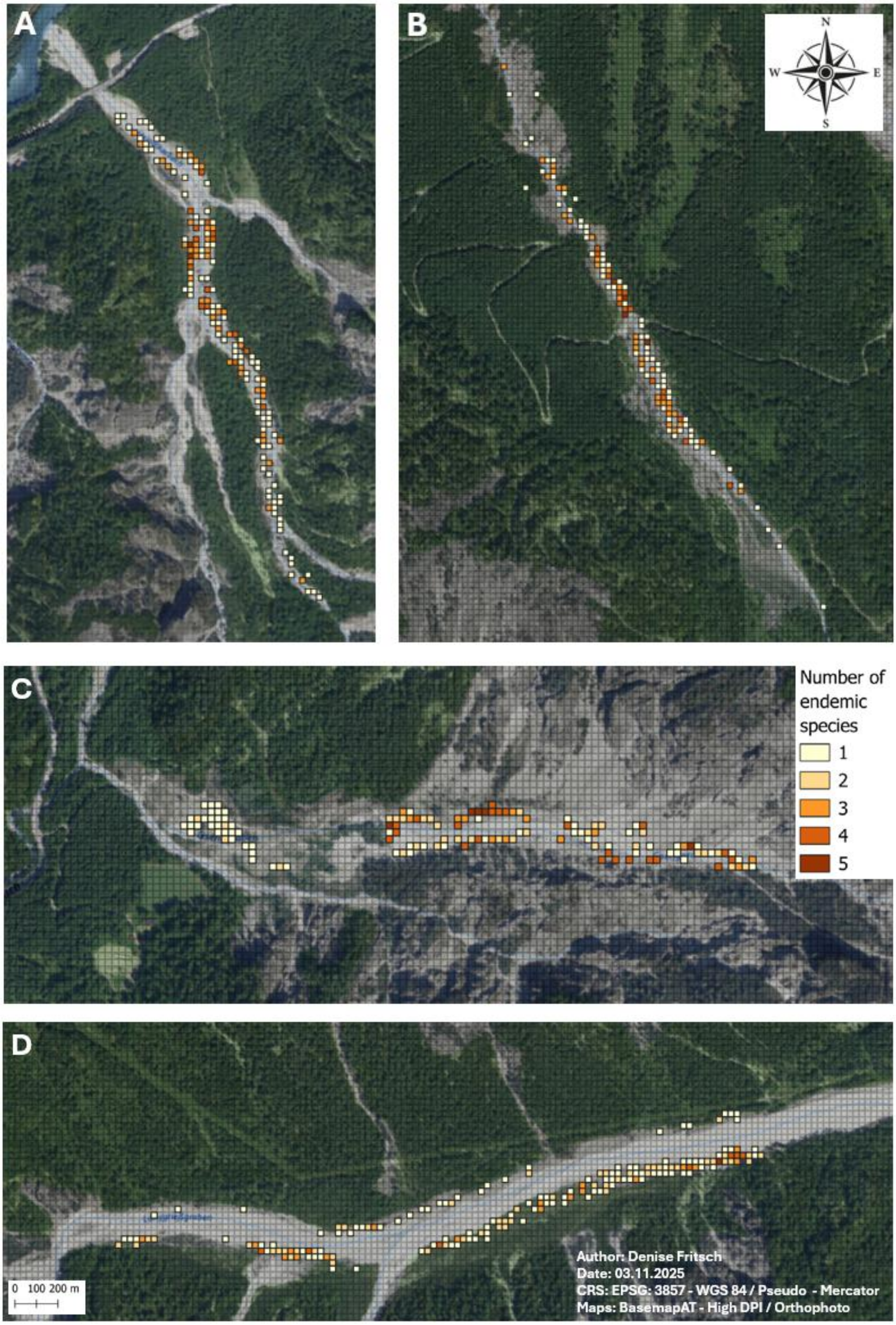

Figure 20 *Maps of the distribution of the endemic plant species on the Haindlkar (A), Kühgraben (B), Gseng (C) and Langgries (D). The number of species was clustered within a grid of 15 m x 15 m fields. The darker the colour, the more plant species occurred in one field with up to 5 endemic species per grid. Maps were created using QGIS version 3.34.12.*

3.6.2 Effect of environmental parameters on the abundance of endemic plants

The results of the GLMM for *Biscutella laevigata* ssp. *austriaca* indicated that altitude level (MASL) and the proportion of block debris significantly influenced its abundance. In addition, the total coverage showed a strong correlation to the abundance of this species ($p < 0.05$). Specifically, the abundance of *B. laevigata* ssp. *austriaca* increased with higher vegetation cover and a greater proportion of block debris but decreased with increasing altitude.

For *Galium truniacum*, the analysis showed that total cover had a strong correlation to its abundance and MASL, the proportions of block and coarse debris, and average slope inclination all had a significant effect on the abundance of this species ($p < 0.05$). The abundance of *G. truniacum* increased with higher vegetation cover, greater altitude, and a larger proportion of coarse debris. In contrast, abundance decreased in areas with a higher proportion of block debris and steeper slopes, being highest in areas with a gentler inclination.

The analysis of *Hieracium porrifolium* revealed that block debris, slope inclination, and radiation significantly influenced its abundance ($p < 0.05$). The species was more abundant at sites with lower proportions of block debris, gentler slopes, and reduced radiation levels, indicating a preference for shadier areas with less steep terrain.

In the case of *Cerastium carinthiacum* ssp. *carinthiacum*, MASL had a significant effect on the abundance ($p < 0.05$). The abundance of this species increased with elevation, reaching its highest values at altitudes above 900 m a.s.l. (Figure 21).

The remaining endemic plant species found in the study area were too rare for statistical analysis. The results of the four GLMMs with all factors can be found in the Appendix (Table A.2)

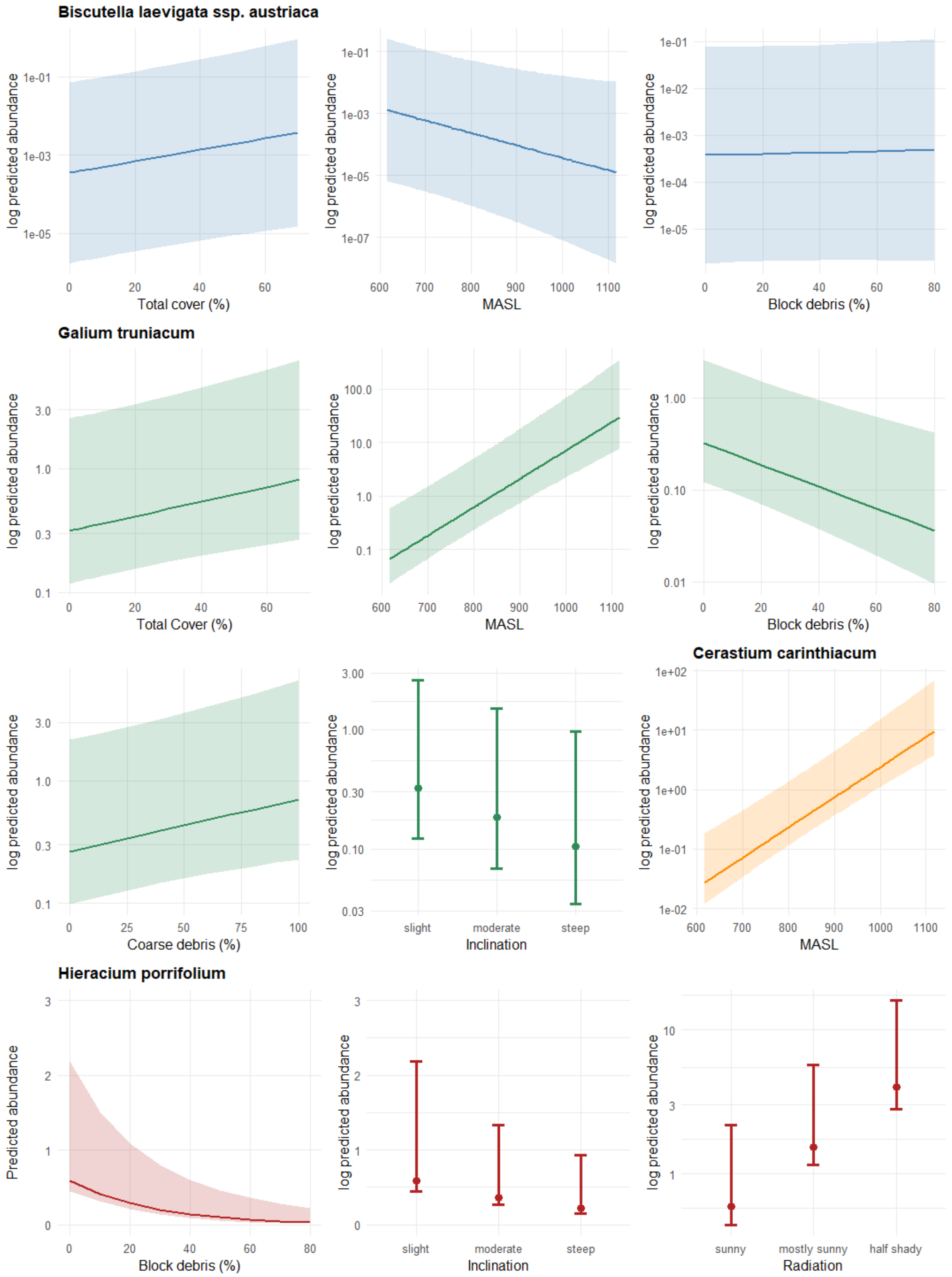

Figure 21 *The predicted abundance of* Biscutella laevigata *ssp.* austraca, Galium truniacum, Cerastium carnithiacum *ssp.* carinthiacum *and* Hieracium porrifolium, *plotted against the significant environmental parameters of the GLMMs. The predicted abundance was calculated using the respective GLMM and the actual abundance of the species in the field. The y-axes are plotted as a logarithmic scale calculated from a decimal logarithm to compensate for the rarity of species in the plots. 95% confidence intervals are shown for each parameter.*

3.6.3 Effect of environmental parameters on the fitness of endemic plants

The potential influence of environmental parameters on the fitness of the endemic plant species was also tested. For *Biscutella laevigata* ssp. *austriaca*, the results showed that MASL had a significant effect on leaf size ($p < 0.05$). With increasing altitude, individuals developed larger leaves, reaching sizes of up to 8 cm.

For *Galium truniacum*, slope exposure and the proportion of coarse debris significantly influenced plant height ($p < 0.05$). Individuals growing in areas with a higher proportion of coarse debris attained greater heights. The tallest specimens were recorded on west-facing slopes, particularly on the Gseng, where *G. truniacum* reached heights of up to 25 cm. No major differences in height were observed among the other slopes.

The results of the GLM for *Hieracium porrifolium* indicated that both the proportion of block debris in the substrate and slope exposure significantly affected leaf size ($p < 0.05$). Leaf size increased with a higher proportion of block debris. Regarding slope exposure, the largest leaves were recorded on north-facing slopes, corresponding to the Haindlkar, where leaves reached up to 15 cm. Slightly smaller leaves were found on the Langgries (east-facing) and Kühgraben (south-facing) sites, with sizes up to 12 cm, while the smallest leaves developed on the Gseng (west-facing) site, reaching up to 9 cm.

For *Cerastium carinthiacum* ssp. *carinthiacum*, the analysis showed that MASL significantly influenced plant height ($p < 0.05$). In the final model, the proportion of fine debris was also included, as it improved the explanatory power of the model, although it was not itself significant ($p > 0.05$). Plant height increased with altitude, reaching up to 13 cm at elevations between 1000 and 1100 m a.s.l. (Figure 22).

The remaining endemic plants found in the research area were too rare for statistical analysis. The results of the four GLMs with all factors can be found in the Appendix (Table A.3).

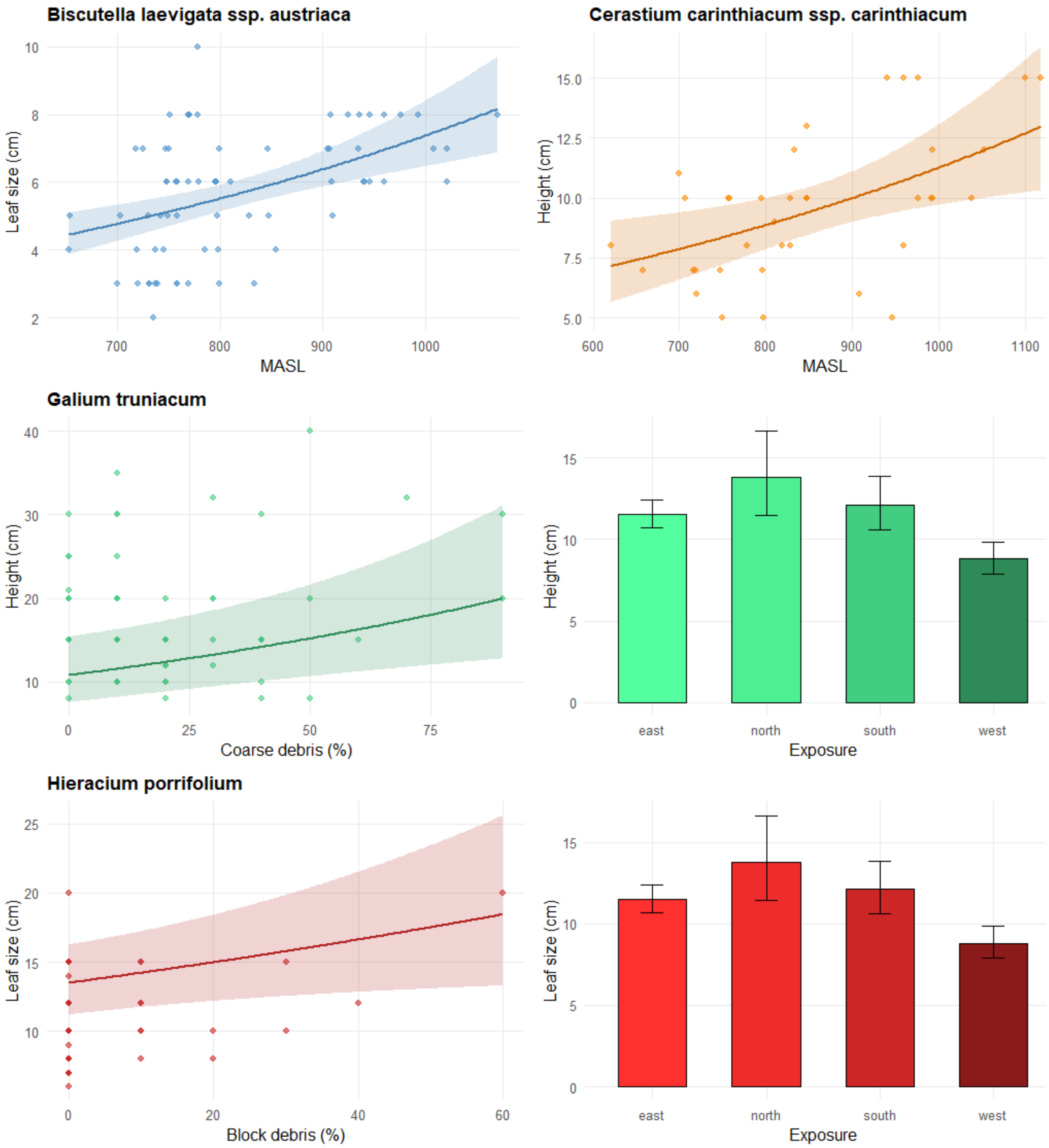

Figure 22 *Measured fitness parameters (leaf size or height) of* Biscutella laevigata *ssp.* austriaca, Cerastium carinthiacum *ssp.* carinthiacum, Galium truniacum *and* Hieracium porrifolium *plotted against the significant environmental parameters of the GLMs. 95% confidence intervals are shown for the parameters as well as the original data as points.*

4 Discussion

4.1 Vegetation of calcareous scree slopes

How is the overall vegetation influenced by the environmental requirements of the habitat?

The vegetation patterns on calcareous scree slopes are shaped by a complex interplay of geomorphological and microclimatic conditions. Across all investigated slopes, three major ecological domains can be distinguished, each representing a characteristic combination of disturbance intensity, substrate stability, and microclimatic regime. The first domain is typically located in the central part of the slope, where fluviatile processes and constant debris movement prevent vegetation from establishing. The only exceptions here are seedlings of tree species that may germinate temporarily but are likely to be displaced during the next heavy rainfall event, and occasional individuals of *Petasites paradoxus*, which remain rather small in size. The second domain extends adjacent to the active parts of the scree slopes. These areas are semi-active – small landslides may still occur occasionally – but stable enough for the establishment of characteristic scree vegetation. The vegetation in this zone usually consists of Petasitetum paradoxi communities (BEGER, 1922). The third domain is generally located at the margins of the scree slopes, where inclination is lower and the substrate remains undisturbed for longer periods. Here, the typical vegetation belongs to the Erico-Pinetum mugo community (ZÖTTL, 1951; GREIMLER, 1997).

Between these three main domains, several additional plant communities were identified. In the highest parts of the Haindlkar investigated in this study, forest vegetation extended into the outer edges of the slope. Due to the scree slope being relatively narrow at this point, the vegetation on the margins partly corresponds to middle- and high-montane spruce-fir-beech forests, featuring characteristic species such as *Acer pseudoplatanus*, *Fagus sylvatica*, and herbaceous species including *Helleborus niger* and the regionally typical *Heracleum austriacum* ssp. *austriacum* (FISCHER, 2018). On the Gseng, particularly in areas where the substrate had remained stable for longer periods and larger rocks were present, Hieracio humilis-Potentilletum caulescentis communities (GREIMLER, 1997) were found, especially in warmer parts of the slope. On the Langgries, where surface water emerged, Asplenio-Cystopteridetum communities (LIPPERT, 1966) were identified, characterised by higher abundances of *Asplenium viride* and *Moehringia muscosa*. On the Kühgraben, *Silene glareosa*-communities (ENGLISCH *et al.* in GRABHERR & MUCINA, 1993) were recorded. This association represents an early successional stage of Petasitetum paradoxi, typically occurring on steep fine-grained to coarse-grained scree slopes with southern exposure. Consequently, these sites are characterised by sunny, warm conditions and strong surface desiccation (GREIMLER, 1997), which is particularly the case for the Kühgraben.

The occurrence of these various plant communities illustrates how the different structural and microclimatic characteristics of each scree slope form a mosaic of microhabitats. One of the most influential factors shaping vegetation is the duration and intensity of solar radiation (WU *et al.*, 2014). Due to the different cardinal directions, different temperature conditions prevailed on the four slopes, resulting in site-specific microclimates confirmed by the data logger measurements. Structural differences further modified the local environment. The Haindlkar showed a clear separation of coarse and fine debris which was accumulated along the margins and pronounced runoff channels indicated substantial debris displacement during heavy rainfall. The Gseng, in contrast, lacked forested margins and was bordered instead by rugged cliffs supplying a continuous input of fresh rubble. At the Langgries, a broad band of long-stabilised scree allowed the development of additional vegetation, creating a distinct microhabitat and the Kühgraben differed by its markedly steeper inclination and its extension into higher elevations. Correspondingly, 48 of the recorded species occurred exclusively on a single scree slope, underscoring the strong influence of local habitat heterogeneity. This pattern is consistent with the concept of "hotspots within hotspots" proposed by CAÑADAS et al. (2014), which suggests that even within regions of already high biodiversity, fine-scale environmental variation can generate additional centres of species richness.

The analysis of species composition on the calcareous scree slopes confirmed that various factors influence the distribution and abundance of vascular plant species and that these factors converge in this environment.

In detail, vegetation cover and radiation showed a strong positive correlation, which can be explained by the fact that areas with denser vegetation were also categorised as shadier in this study (note that the radiation scale ranged from "sunny" to "shady"). This implies that, on scree slopes where vegetation cover typically reaches only around 10% (ELLMAUER *et al.*, 2020), plants experience higher levels of radiation stress (RAMSKOGLER *et al.*, 2023; CREPAZ *et al.*, 2021). Altitude and slope inclination were also positively correlated, as higher altitudes were generally associated with steeper scree slopes, since each of the slopes became steeper with increasing elevation. Furthermore, several relationships were observed among the debris size classes. Larger debris fractions were positively correlated with each other but negatively

correlated with smaller debris fractions. This pattern suggests that vegetation on scree slopes tend to be adapted either to fine debris or to coarse debris, but rarely to both simultaneously.
This can be explained by the differing mechanical and ecological properties of the substrate. Fine debris tends to accumulate in more stable areas, favouring species adapted to relatively settled conditions with higher proportions of organic matter and, consequently, greater nutrient availability (PÉREZ, 2009). By contrast, species growing on coarser debris are typically adapted to more mobile and coarser-grained habitats, suggesting that extensive root systems play a crucial role in stabilising the substrate. Similar findings were reported by GIUPPONI *et al.* (2023), who also observed that vegetation typical of unstable screes exhibited lower plant cover compared to that of more stable sites, where cover values were considerably higher. This pattern is also reflected in the results of this study, where vegetation cover and fine debris were consistently positively correlated, indicating that higher proportions of fine material support denser vegetation.

Linking these results back to the three slope domains described before reveals how debris size, stability, and vegetation cover interact. Plant communities such as the Petasitetum paradoxi and *Silene glareosa*-associations typically exhibit lower vegetation cover, whereas the Erico-Pinetum mugo community, which occurs in more stable marginal areas, develops substantially higher cover values (GREIMLER, 1997). This also leads to less radiation in parts of higher vegetation cover as bushes such as *Pinus mugo* and stunted individuals of *Pinus sylvestris* present in the Erico-Pinetum mugo community cause shading. Hence, the environmental parameters that influence this habitat and thus the vegetation are therefore closely intertwined and interact strongly in their impact.
However, these patterns also illustrate that typical vascular plant species inhabiting calcareous scree slopes exist within a very narrow ecological window. On the one hand, many scree specialists depend on a certain degree of substrate movement, which prevents more competitive species from establishing and dominating once the scree has remained stable for extended periods. On the other hand, excessive movement of the debris becomes detrimental, as it can disturb or uproot the scree vegetation beyond its tolerance limits.

4.2 Endemic vascular plants of calcareous scree slopes

Where do endemic plant species occur on calcareous scree slopes in the investigated area and how are they affected by the present environmental conditions?

In summary, the highest number of endemic vascular plants was recorded on the Gseng. Notably, three endemic species were found exclusively on this slope. On the remaining three scree slopes, the same number of endemic species occurred, although the species composition varied between sites. When comparing all endemic species, it becomes evident that each has specific habitat requirements and responds differently to environmental factors.

The results for *Biscutella laevigata* ssp. *austriaca* indicate that this species mainly occurs in sites with higher vegetation cover and a slightly higher proportion of block debris, while being more frequent at lower altitudes. On the scree slopes, this endemic species was observed in areas where other plant species were moderately abundant and where larger debris fractions were present, as well as in places where the substrate was relatively stable but still subject to occasional movement. The environmental requirements of *B. laevigata* ssp. *austriaca* thus appear to span a broader amplitude than those of other species in this habitat. It tolerates sites with minor landslides but also persists in more stable substrates where competition from other species is stronger. FAULHABER & PARTZSCH (2018) found a negative correlation between vegetation biomass and population size in *B. laevigata*, suggesting that this species prefers sites with less competition from other species and that competitive processes play an important role. Similar relationships between plant cover and debris characteristics on screes have also been reported by GIUPPONI *et al.* (2022), although not specifically for this subspecies. They found that plant cover increases with a higher proportion of fine sediments. Nevertheless, *B. laevigata* ssp. *austriaca* is one of the species classified as belonging to the Petasitetum paradoxus community (GREIMLER, 1997), which suggests that this species thrives best in slightly disturbed locations with less competition.

The adaptations of *Biscutella laevigata* ssp. *austriaca* also support the above interpretation of its preferred habitat conditions. BILLINGS (1974) notes that rosette-forming plants are often pioneers in highly disturbed environments, which aligns well with the frequent occurrence of this species in sites where substrate movement is likely. A morphological trait further supporting this interpretation is its system of long, highly branched roots, which help stabilise loose surfaces and enable persistence on shifting scree (JENNY-LIPS, 1930).

Galium truniacum was most common in plots with higher vegetation cover and greater proportions of coarse debris, whereas it occurred less frequently where block debris dominated. This species also preferred higher altitudes and gentle to moderately inclined slopes. These findings suggest that *G. truniacum* favours environments characterised by smaller debris sizes and moderate vegetation cover, and that it is adapted to cooler conditions at higher elevations. GREIMLER (1997) states that the society this species mainly occurs in, the *Athamantha cretensis-Trisetum alpestre*-society, has its optimum in open rocky grasslands and rocky crevice communities on fine-grained and settled scree slopes, which also accounts for *G. truniacum*. An adaptation typical of plants in higher elevations, and also exhibited by this species, is the production of secondary pigments, which impart a purple colouration and protect photosynthetic tissues from intense insolation (NEILL, 2002).

The results for *Hieracium porrifolium* showed that this species was most abundant in sites with greater shading, lower proportions of block debris, and gentler slopes. This pattern is consistent with field observations, where *H. porrifolium* was particularly common in the lower parts of the Gseng and Langgries. Here, the substrate remained stable over a longer period of time, allowing accumulation of fine debris and primary succession to take place, resulting in increased vegetation cover. On the Haindlkar and Kühgraben, *H. porrifolium* was likewise found in less active slope sections. Outside these areas, the species occurred only sporadically. This indicates that *H. porrifolium* is best adapted to semi-active or resting scree areas, where other vegetation can establish more densely. These findings are consistent with GREIMLER (1997), who describes the Erico-pinetum mugo community, in which *H. porrifolium* also mainly occurred on the sites, as typically colonising stabilised and only occasionally disturbed scree sites. The species also exhibits morphological adaptations to drought and radiation stress, such as rolled or folded leaves and a blue-grey leaf surface, which reduce water loss and protect against insolation (FISHER, 1952).

For *Cerastium carinthiacum* ssp. *carinthiacum*, altitude had the strongest influence on its occurrence. The species was most common at higher altitudes, suggesting an adaptation to colder climatic conditions associated with elevation. This agrees with GREIMLER (1997), who identified the species as typical of alpine plant communities, indicating that it may also occur at elevations higher than those included in the present study.
In addition, *C. carinthiacum* ssp. *carinthiacum* appeared to be influenced by further factors besides altitude. Based on point mapping, this species seems to prefer loose substrates with low vegetation cover, as it showed minimal overlap with *H. porrifolium*, which occupies the opposite habitat type. Consistent with its occurrence in unstable scree habitats, the species possesses long, highly branched roots – similar to those of *B. laevigata* ssp. *austriaca* – which enhance surface stabilisation in coarse, mobile debris (JENNY-LIPS, 1930).

Although the remaining endemic species were too rare for statistical analysis, point mapping nonetheless revealed distinct habitat associations. *Campanula cespitosa* and *Papaver alpinum* ssp. *alpinum* were more frequent in areas with low vegetation cover, loose substrate, and larger debris fractions. This is consistent with findings that *C. cespitosa* favours rocky, open scree sites within the Alps (MÜLLER *et al.*, 2017) and that *Papaver* species typically occupy coarse, unstable scree (BITA-NICOLAE *et al.*, 2025). *Asperula neilreichii* and *Dianthus plumarius* ssp. *blandus* were commonly associated with *G. truniacum*, indicating a preference for denser vegetation, finer debris, and higher altitudes. The findings on *D. plumarius* ssp. *blandus* are also supported by KÖPPL & OBERKLAMMER (2017), who report that this species thrives in open, sunny, yet well-drained scree habitats. Conversely, *Heracleum austriacum* ssp. *austriacum* and *Primula clusiana* exhibited patterns similar to *H. porrifolium*, occurring mainly in sites where the scree had stabilised over longer periods and vegetation cover was greater, particularly along scree margins. Regional flora and vegetation surveys confirm the occurrence of these species in more stabilised scree edges with higher vegetation cover (LANDMANN, 2015).

4.3 Fitness of endemic vascular plants on calcareous scree slopes

How do environmental parameters affect plant fitness of endemic vascular plants?

Analysis of the fitness of endemic vascular plants has shown that it is also fundamentally influenced by the conditions and dynamics of the scree slopes. In addition, new insights were gained, particularly regarding the fitness of the four endemic species studied.

For *Biscutella laevigata* ssp. *austriaca* and *Cerastium carinthiacum* ssp. *carinthiacum*, altitude had a significant effect on plant fitness. Both taxa exhibited higher individual fitness measures at greater elevations, as also reported by FAULHABER & PARTZSCH (2018) and HORNEMANN (2012). While this pattern aligns with the altitudinal abundance trend of *C. carinthiacum* ssp. *carinthiacum*, which was more frequent at higher elevations, it contrasts with the abundance pattern of *B. laevigata* ssp. *austriaca*, which was more common at lower altitudes in this study. A likely explanation why the fitness of plants is better at higher elevations is that colder, high-altitude conditions favour physiological or demographic traits that enhance individual fitness – such as slower growth and greater resource conservation – even when overall population densities are lower (KÖRNER & HILTBRUNNER, 2021; DOLEŽAL *et al*., 2020). These results are consistent with findings that *B. laevigata* ssp. *austriaca* exhibited higher fitness but lower abundance at higher altitudes. In contrast, *C. carinthiacum* ssp. *carinthiacum* showed higher fitness but also higher abundance at higher altitudes, suggesting that high-altitude conditions also favour population fitness of this species.

Although high-altitude sites receive greater solar and UV radiation, several experimental and review studies indicate that temperature – and its influence on metabolic rates and the length of the growing season – is often the dominant determinant of plant performance in alpine environments (NOTARNICOLA *et al.*, 2021; SEDEJ *et al.*, 2020). Therefore, the lower temperatures measured at higher altitudes on the investigated scree slopes support the interpretation that cooler thermal conditions, rather than increased radiation per se, explain the enhanced fitness values observed in these species.

Similar to its abundance pattern, the fitness of *Galium truniacum* was higher in areas with greater proportions of coarse debris and on the west-facing Gseng slope. The Gseng is characterised by exposed rocky headwalls and a continuous supply of fresh rubble, with no forested margins, creating an environment dominated by coarse debris and open substrate. Species on this slope thus appear adapted to dynamic, rocky conditions - consistent with the findings of HEISELMAYER & GRABNER (2009), who emphasised that debris input through rockfall and the absence of forest edges foster distinctive scree plant communities.

In contrast to the abundance results for *Hieracium porrifolium* – where this species was more common in areas with lower proportions of block debris – the fitness analysis revealed that individuals performed better at sites with higher percentages of block debris. Moreover, *H. porrifolium* displayed higher fitness on the Haindlkar, where, unlike at Langgries and Gseng, no clear spatial accumulation of individuals was observed. These findings for *H. porrifolium* appear to be novel, as no comparable studies examining this specific relationship between grain sizes and fitness of *H. porrifolium* were identified in the literature.
However, the higher proportion of block debris on the Haindlkar may indicate resting substrate with reduced disturbance, conditions that were also proposed to favour the abundance of this species in Chapter 4.2. On the Haindlkar, "islands" of large boulders were common, features not observed on the other three slopes. Such large rocks, known as boulder dams, can obstruct the downslope movement of scree, thereby reduce disturbance and promote the accumulation of fine material (PÉREZ, 2009). This local topography likely creates microhabitats favourable to *H. porrifolium*, potentially explaining the significantly larger individuals recorded on the Haindlkar.

5 Conclusion and Outlook

In conclusion, this study demonstrates that the distribution and composition of vegetation on calcareous scree slopes in the Eastern Calcareous Alps are shaped by a complex interplay of environmental factors. These factors vary considerably inside as well as between slopes, creating distinct ecological spaces in close proximity and driving the development of different plant communities within this dynamic habitat. Three main ecological domains could be identified, primarily determined by grain-size composition, substrate movement, radiation, inclination, altitude level, vegetation cover, and the associated presence of organic matter and fine sands. It also became evident that the characteristic scree vegetation occupies a narrow ecological niche. Many environmental conditions can quickly become limiting, reflecting the high degree of adaptation required for survival on unstable scree.

The endemic vascular plants were particularly specialised, with both their abundance and fitness influenced by multiple environmental factors. Each taxon responded to a unique combination of conditions, confirming that every endemic species occupies its own ecological niche within the broader scree ecosystem. The contrasting habitat preferences of *Hieracium porrifolium* and *Cerastium carinthiacum* ssp. *carinthiacum* exemplify this clearly, as their occurrences rarely overlapped.

Several novel findings emerged from this study, particularly concerning the relationships between endemic species and the proportions of different grain-size classes. No previous research has examined these endemics in relation to three distinct debris sizes, making these results an important contribution to the ecological understanding of the flora of Alpine scree. Additionally, the fitness analyses of the endemic taxa yielded largely new insights, as no earlier studies have assessed how fitness traits of these species in the Ennstal Mountains relate to environmental parameters. Nevertheless, there were limitations to this study. For example, the fitness of endemic vascular plants could have been measured even better and in a more targeted manner. To this end, it would have been useful to take selective measurements of temperature and solar radiation at the locations where endemic species occur.

Although the vegetation ecology of scree slopes, along with scree dynamics and associated environmental gradients, has been widely studied, significant knowledge gaps remain – especially regarding rare and endemic vascular plants. While their general distributions and associated plant communities are known, the detailed ecological requirements of these highly localised species are still only partially understood. This thesis contributes to filling some of these gaps, but further research will be essential to fully understand these endemic species and to ensure their effective conservation. Given their narrow habitat tolerances and restricted ranges, endemic species represent a particularly vulnerable and valuable component of Alpine biodiversity.

6 References

AESCHIMANN D., LAUBER K., MOSER D. M., THEURILLAT J.-P. (2004): Flora Alpina: Ein Atlas sämtlicher 4500 Gefässpflanzen der Alpen. Haupt Verlag, Bern.

BATES D., MÄCHLER M., BOLKER B., WALKER S. (2015): Fitting Linear Mixed Effects Models Using lme4. *Journal of Statistical Software*, 67 (1), 1-48.

BEGER H. K.E. (1922): Assoziationsstudien in der Waldstufe des Schanfiggs. Mitt. Bot. Museum, Universität Zürich, 96.

BILLINGS W. D. (1974): Adaptations and Origins of Alpine Plants. *Arctic and Alpine Research*, 6 (2), 129-142.

BIȚĂ-NICOLAE C., MOGÎLDEA D., POP O. G. (2025): Investigating Endemic Alpine Communities of *Papaver corona-sancti-stephani* and *Cerastium lerchenfeldianum* in the Southern Carpathians. *Diversity*, 17 (4), 283.

BRADSHAW A. D. (1971): Ecological Genetics and Evolution. Blackwell Scientific Publications, 20-50.

BRAUN-BLANQUET J. (1964): Pflanzensoziologie: Grundzüge der Vegetationskunde (3. Auflage). Springer Verlag, Berlin.

COWIE R.H., BOUCHET P., FONTAINE B. (2022): The Sixth Mass Extinction: fact, fiction or speculation? *Biological Reviews*, 97 (2), 449-850.

CREPAZ H., NIEDRIST G., WESSELY J., ROSSI M., DULLINGER S. (2021): Resident vegetation modifies climate-driven elevational shift of a mountain sedge. *Alpine Botany*, 131, 13-25.

DOLEZAL J., KURNOTOVA M., STASTNA P., KLIMESOVA J. (2020): Alpine plant growth and reproduction dynamics in a warmer world. *New Phytologist*, 228 (4), 1295-1305.

ELLMAUER T., IGEL V., KUDRNOVSKY H., MOSER D., PATERNOSTER D. (2019): Monitoring von Lebensraumtypen und Arten von gemeinschaftlicher Bedeutung in Österreich 2016-2018 und Grundlagenerstellung für den Bericht gemäß Artikel17 der FFH-Richtlinie im Jahr 2019. Teil 1: Artikel 11 – Monitoring. Umweltbundesamt GmbH, im Auftrag der österreichischen Bundesländer, Wien.

FATH B. (2019): Encyclopaedia of Ecology (Second Edition). Elsevier, Oxford.

FAULHABER M., PARTZSCH M. (2018): *Biscutella laevigata* L. – a post glacial botanical relict in Central Germany: population structure and plant-plant interaction. *Hercynia – Ökologie und Umwelt in Mitteleuropa*, 51, 58-79.

FISCHER M. A. (2018): Towards an Excursion Flora for Austria and all the Eastern Alps. *Botanica Serbica*, 42 (1), 5-33.

FISCHER M. A., OSWALD K., ADLER W. (2008): Exkursionsflora für Österreich, Liechtenstein und Südtirol (3. Auflage). Land Oberösterreich, Biologiezentrum der Oberösterreichischen Landesmuseen, Linz.

FISHER F. J.F. (1952): Observations on the Vegetation of Screes in Canterbury, New Zealand. *Journal of Ecology*, 40 (1), 156-167.

FOX J., WEISBERG S. (2019): An R companion to Applied Regression, Third edition. Sage, Thousand Oaks CA.

GEOSPHERE AUSTRIA-Bundesanstalt für Geologie, Geophysik, Klimatologie und Meteorologie, Wien. `https://maps.geosphere.at/de` (last access: 17.11.2025).

GIUPPONI L., LEONI V., PEDRALI P., ZUCCOLO M., CISLAGHI A. (2023): Plant cover is related to vegetation and soil features in limestone screes colonization: A case study in the Italian Alps. *Plant and Soil*, 483, 495-513.

GRABHERR G., MUCINA L. (eds) (1993): Die Pflanzengesellschaften Österreichs, Teil 2. Gustav Fischer Verlag, Jena, 523.

GREIMLER J. (1997): Pflanzengesellschaften und Vegetationsstruktur in den südlichen Gesäuse-Bergen (nordöstliche Kalkalpen, Steiermark). Landesmuseum Joanneum Graz, Austria.

GRIEBL N. (2021): Die Kosmos Alpenflora, Franckh-Kosmos Verlag, Stuttgart.

HEISELMAYER P., GRABNER S. (2009): Das Wimbachgries, ein Juwel des Nationalparks Berchtesgaden (Bayern, Deutschland). *Tuexenia*, 2, 195.

HORNEMANN G. (2012): Population size, environmental variability and plant performance. Dissertation, Universitätsbibliothek Marburg.

JENNY-LIPS H. (1930): Vegetationsbedingungen und Pflanzengesellschaften auf Felsschutt: Phytosoziologische Untersuchungen in den Glarner Alpen. *Botanisches Zentralblatt*, 46 (2).

KÖPPL W., OBERKLAMMER I. (2017): Dianthus plumarius ssp. blandus – Distribution and Habitat Features. 6th Symposium for Research in Protected Areas, Conference Volume, 327-330.

KÖRNER C., HILTBRUNNER E. (2021): Why is the Alpine Flora Relatively Robust against Climate Warming? *Diversity*, 13 (8), 383.

LARCHER L., KAINMÜLLER C., WAGNER J. (2010): Survival types of high mountain plants under extreme temperatures. *Flora – Morphology, Distribution, Functional Ecology of Plants*, 205 (1), 3-18.

LIPPERT W. (1966): Die Pflanzengesellschaften des Naturschutzgebietes Berchtesgaden. Ber. Bayerischer Botaniker Gesellschaft, 39, 67-122.

MALCOLM J. R., CANRAN L., NEILSON R. P., HANSEN L., HANNAH L. (2006): Global Warming and Extinctions of Endemic Species from Biodiversity Hotspots. *Conservation Biology*, 20 (2), 263-594.

MERTZ P. (2002): Pflanzenwelt Mitteleuropas und der Alpen. Nikol Verlagsgesellschaft, Hamburg, 410-411.

MITTERMEIER R. A., ROBLES G. P., HOFFMANN M., PILGRIM J., BROOKS T., MITTERMEIER C. G. (2005): Hotspots Revisited: Earth's Biologically Richest and Most Endangered Terrestrial Ecoregions. Washington DC: Conservation International.

MÜLLER N., KOLLMANN J., KUDRNOVSKY H., KÜMMERLING M., LENTNER R. (2017): Proceedings 15th International Alpine Workshop & 4th International River Conference Tagliamento 2017. University of Applied Sciences Erfurt, Dep. Landscape Management & Restoration Ecology.

MYERS N., MITTERMEIER R. A., MITTERMEIER C. G., DA FONSECA G. A.B., KENT J. (2000): Biodiversity hotspots for conservation priorities. *Nature*, 403, 853-858.

NATIONALPARKS AUSTRIA; Nationalpark Gesäuse. `https://www.nationalparksaustria.at/de/nationalpark-gesaeuse.html` (last access: 05.11.2025).

NEILL S. O. (2002): The functional role of anthocyanins in leaves. Dissertation, Biological Sciences, University of Auckland.

NOROOZI J., ZARE G., SHERAFATI M., MAHMOODI M., MOSER D., ASGARPOUR Z., SCHNEEWEISS G. M. (2019): Patterns of Endemism in Turkey, the Meeting Point of Three Global Biodiversity Hotspots, Based on Three Diverse Families of Vascular Plants. *Frontiers in Ecology and Evolution*, 7.

NOTARNICOLA R. F., NICOTRA A. B., KRUUK L. E.B., ARNOLD P. A. (2021): Tolerance of Warmer Temperatures Does Not Confer Resilience to Heatwaves in an Alpine Herb. *Frontiers in Ecology and Evolution*, 9.

OKSANEN J., BLANCHET G., KINDT R., LEGENDRE P., MINCHIN P. R., O'HARA R. B., SIMPSON G. L., SOLYMOS P., H. STEVENS M. H., WAGNER H. (2025): vegan: Community Ecology Package, depends: permute.

PEARCE-KELLY P., ALTIERI A. H., BRUNO J. F., CORNWALL C. E., MCFIELD M., MUNIZ-CASTILLO A. I., ROCHA J., SETTER R. O., SHEPPARD C., ROMAN-CUESTA R. M., YESSON C. (2025):

Considerations for determining warm-water coral reef tipping points. *Earth System Dynamics*, 16 (1), 275-292.

Pérez F. L. (2009): Phytogeomorphic Influence of Stone Covers and Boulders on Plant Distribution and Slope Processes in High-Mountain Areas. *Geography Compass*, 3 (5), 1774-1803.

Rabitsch W., Essl F. (2008): Endemiten in Österreich: Selten und schützenswert. Umweltbundesamt Österreich, Wien.

Ramskogler K., Knoflach B., Elsner B., Erschbamer B., Haas F., Heckmann T., Hofmeister F., Piermattei L., Ressl C., Trautmann S., Wimmer M. H., Geitner C., Stötter J., Tasser E. (2023): Primary succession and its driving variables – a sphere-spanning approach applied in proglacial areas in the upper Martell Valley (Eastern Italian Alps). *Biogesciences*, 20 (14), 2919-2939.

Remschak C. (2022): Emergenzfallen an Quellen, 2020-2022. Bericht, Nationalpark Gesäuse GmbH.

Sánchez-Fernández D., Jiménez-Jiménez A., Fox R., Dennis R. L.H., Lobo J. M. (2025): Identifying biodiversity hotspots over time: Stability, sampling bias, and conservation implications. *Global Ecology and Conservation*, 59.

Schratt-Ehrendorfer L., Niklfeld H., Schröck C., Stöhr O. (2022): Rote Liste der Farn- und Blütenpflanzen Österreichs. Dritte, völlig neu bearbeitete Auflage. Stapfia, 0114, 1-357.

Sedej T. T., Erznožnik T., Rovtar J. (2019): Effect of UV radiation and altitude characteristics on functional traits and leaf optical properties in *Saxifraga hostii* at the alpine and montane site in the Slovenian Alps. *Photochemical and Photobiological Sciences*, 19 (2).

Silander J. A. (2013): Encyclopaedia of Biodiversity (Third Edition). Elsevier, Volume 1, 333-349.

Suchopar A. (2024): Arbeitsanweisung pH-Wert-Bestimmung in 0.01 M $CaCl_2$. Unpublished.

Thalmann M., Santelia D. (2017): Starch as a determinant of plant fitness under abiotic stress. *New Phytologist*, 214 (3), 943-951.

Umweltbundesamt Österreich (2020): Ellmauer T., Igel V., Kudrnovsky H., Moser D., Paternoster D. (2020): Monitoring von Lebensraumtypen und Arten von gemeinschaftlicher Bedeutung in Österreich 2016-2018 und Grundlagenerstellung für den Bericht gemäß Art. 17 der FFH-Richtlinie im Jahr 2019. Teil 3: Kartieranleitungen. Im Auftrag der österreichischen Bundesländer. Umweltbundesamt GmbH, Wien.

WEGENERNET DATENPORTAL. Wegener Center für Klima und Globalen Wandel. https://wegenernet.org/portal/ (last access: 17.11.2025).

WICKHAM H. (2016): ggplot2: Elegant Graphics for Data Analysis (2nd edition). Springer International Publishing, New York.

WU D., ZHAO X., ZHAO W., TANG B., XU W. (2014): Response of vegetation to temperature, precipitation and solar radiation time-scales: A case study over mainland Australia. *IEEE Geoscience and Remote Sensing Symposium*, Quebec City, 855-858.

ZENG K., HE S., ZHAN P. (2025): Inevitable global coral reef decline under climate change-induced thermal stresses. *Nature*, 6 (827).

ZÖTTL H. (1951): Die Vegetationsentwicklung auf Felsschutt in der alpinen und subalpinen Stufe des Wettersteingebirges. Jahresblatt Ver. Schütze Alpenpflanzen und -Tiere. 16, 10-74.

7 Appendix

Figure A.1 *Photos of the Haindlkar. Lower section (left), middle section (middle) and upper section (right).*
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Figure A.2 *Photos of the Gseng. Lower section (left), middle section (middle) and upper section (right).*
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Figure A.3 *Photos of the Langgries. Lower section (left), middle section (middle), upper section (right).*
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Figure A.4 *Photos of the Kühgraben with visible anthropogenic alterations. Lower section (top left), middle section (top middle, top right), upper section (bottom left, bottom right).* © Denise Fritsch

Table A.1 List of all species found on the four scree slopes. Species found on all slopes are marked in green, species found on only one slope are marked in yellow.

	Haindlkar	**Gseng**	**Langgries**	**Kühgra-ben**
Acer pseudoplatanus T	x	x		
Fagus sylvatica T	x			
Pinus sylvestris T			x	
Salix eleagnos T		x		
Acer pseudoplatanus Sh	x			
Alnus incana Sh		x		
Frangula alnus Sh			x	
Juniperus communis Sh	x		x	
Larix decidua Sh		x		
Picea abies Sh	x	x		x
Pinus sylvestris Sh	x	x	x	x
Pinus mugo Sh		x	x	
Salix alba Sh		x		
Salix appendiculata Sh		x		
Salix caprea Sh	x			
Salix eleagnos Sh	x	x	x	x
Salix glabra Sh	x			
Salix purpurea Sh	x	x	x	x
Salix waldsteiniana Sh	x	x		
Acer pseudoplatanus H	x	x	x	x
Alnus incana H	x	x	x	x
Amelanchier ovalis H	x			
Berberis vulgaris H	x	x	x	x
Betula pendula H	x	x	x	
Daphne cneorum H	x		x	x
Fagus sylvatica H		x		x
Frangula alnus H	x		x	
Juniperus communis H	x			
Larix decidua H		x	x	
Picea abies H	x	x	x	x
Pinus mugo H	x	x	x	
Pinus sylvestris H	x	x	x	x

Populus tremula H		x		
Rhododendron hirsutum H			x	
Salix alba H		x		
Salix appendiculata H	x	x		x
Salix caprea H	x	x	x	x
Salix eleagnos H	x	x	x	x
Salix glabra H	x	x	x	x
Salix purpurea H	x	x	x	x
Salix waldsteiniana H	x	x		
Achillea clavaenne		x	x	
Achnatherum calamagrostis	x			
Aconitum variegetum agg	x			
Adenostyles glabra	x		x	
Angelica sylvestris	x			
Anthericum ramosum	x	x	x	
Arabis alpina				x
Arabis bellidifolia ssp. *stellulata*	x			
Aruncus dioicus	x			x
Asperula cynanchica	x	x	x	
Asperula neilreichii		x		
Asplenium ruta-muraria		x	x	
Asplenium viride	x		x	x
Aster bellidiastrum	x	x	x	x
Athamantha cretensis	x	x		x
Atropa belladonna			x	
Barbarea vulgaris			x	
Biscutella laevigata ssp. *austriaca*	x	x	x	x
Biscutella laevigata ssp. *laevigata*	x		x	
Buphthalmum salicifolium	x	x	x	x
Calamagrostis epigejos	x	x		x
Calamagrostis varia	x	x	x	x
Campanula cespitosa	x	x	x	x
Campanula cochleariifolia	x	x	x	x
Campanula rotundifolia			x	
Carduus defloratus	x	x	x	x
Carex alba	x	x	x	x

Carex brachystachys	x			
Carex firma	x		x	x
Carex flacca	x	x	x	x
Carex mucronata	x	x	x	x
Cephalanthera longifolia		x		
Cephalanthera rubra		x		
Cerastium carinthiacum ssp. *carinthiacum*	x	x	x	x
Chlorocrepis staticifolia	x	x	x	x
Cirsium cf. *pannonicum*	x	x	x	
Clematis vitalba	x			x
Clinopodium alpinum		x		x
Convallaria majalis	x			
Cyclamen purpurascens	x			
Dactylorhiza maculata	x			
Dianthus plumarius ssp. *blandus*		x	x	x
Dryas octopetala	x	x	x	
Epipactis atrorubens		x		x
Epipactis palustre		x	x	
Equisetum variegatum		x		
Erica carnea	x	x	x	x
Erigeron acris		x		
Erigeron annuus		x		
Eupatorium cannabinum	x	x	x	x
Euphorbia amygdaloides	x		x	x
Euphorbia cyparissias		x		x
Euphrasia salisburgensis	x	x	x	x
Festuca rubra	x	x		x
Galium album	x	x	x	x
Galium lucidum	x	x	x	x
Galium pusillum agg.				x
Galium truniacum	x	x	x	x
Gentianella sp.	x			
Geranium robertianum	x		x	x
Globularia cordifolia	x	x	x	
Globularia nudicaulis			x	

Gymnadenia conopsea	x		x	x
Gymnadenia odoratissima			x	
Gymnocarpium robertianum	x		x	x
Heliosperma pusillum ssp.*pusillum*	x		x	x
Helleborus niger	x		x	
Heracleum austriacum ssp. *austriacum*	x			x
Hieracium bifidum	x	x	x	x
Hieracium glaucum	x	x		x
Hieracium murorum	x		x	x
Hieracium piloselloides		x		
Hieracium porrifolium	x	x	x	x
Hepatica nobilis	x		x	
Hornungia alpina	x	x	x	
Hypericum perforatum		x		
Kernera saxatilis	x	x	x	x
Lactuca muralis	x		x	
Leontodon hispidus	x	x		x
Leontodon incanus	x	x	x	
Leucanthemum atratum		x		
Leucanthemum vulgare agg.		x		
Linaria alpina		x		x
Linum catharticum	x		x	x
Lotus corniculatus	x	x	x	x
Melica nutans	x		x	
Medicago lupulina		x		
Melampyrum sylvaticum	x			
Melilotus albus		x		
Moehringia muscosa	x		x	x
Molinia arundinacea	x	x	x	x
Neottia ovata	x			
Oenothera biennis		x		
Origanum vulgare				x
Orobanche flava			x	x
Papaver alpinum ssp. *alpinum*		x		
Petasites paradoxus	x	x	x	x
Phyteuma spicatum	x			

Pimpinella major				x
Pimpinella saxifraga		x		
Pinguicula alpina	x		x	
Poa alpina	x	x	x	x
Polygala amara	x	x	x	x
Polygala chamaebuxus	x	x	x	x
Polygonatum odoratum	x			
Potentilla caulescens	x	x	x	x
Potentilla erecta	x		x	
Prenanthes purpurea	x			
Primula clusiana	x		x	
Primula auricula	x	x	x	
Ranunculus alpestris	x			
Rhinantus glaciales	x	x	x	x
Rubus saxatilis	x			x
Rumex scutatus	x	x	x	x
Saxifraga caesia	x			x
Saxifraga mutata				x
Scabiosa columbaria ssp. *columbaria*	x	x		x
Selaginella selaginoides	x		x	
Sesleria albicans	x	x	x	x
Silene vulgaris ssp. *glareosa*	x	x	x	x
Solidago virgaurea				x
Stachys alopecuros ssp. *alopecuros*			x	x
Taraxacum ruderalia		x		
Teucrium montanum		x		x
Thesium alpinum	x		x	x
Thymus praecox	x	x	x	x
Tofielda calyculata	x	x	x	x
Trifolium pratense		x		
Valeriana saxatilis	x	x	x	
Verbascum nigrum		x		
Vincetoxicum hirundinaria	x	x	x	x
Viola biflora	x	x	x	x

Table A.2 Results of the analysis of Variance Table of the four GLMMs for the endemic plant species. Analysed were the influence of environmental parameters on *Biscutella laevigata* ssp. *austriaca, Galium truniacum, Hieracium porrifolium* and *Cerastium carinthiacum* ssp. *carinthiacum*. The factors for the significant variables of each model are listed.

		npar	**Sum sq**	**Mean Sq**	**F value**
Biscutella laevigata ssp. *austriaca*	Total.Cover	1	4.4209	4.4209	4.4209
	MASL	1	3.7370	3.7370	3.7370
	Block.debris	1	0.0564	0.0564	0.0564
Galium truniacum	Total.Cover	1	2.880	2.880	2.8797
	MASL	1	39.952	39.952	39.9517
	Inclination	1	8.916	8.916	8.9156
	Block.debris	1	13.598	13.598	13.5983
	Coarse.derbis	1	4.569	4.569	4.5694
Hieracium porrifolium	Radiation	1	78.123	78.123	78.1234
	Inclination	1	9.467	9.467	9.4674
	Block.debris	1	20.658	20.658	20.6580
Cerastium carinthiacum ssp. *carinthiacum*	MASL	1	69.57	69.57	69.57

Table A.3 Results of the analysis of Deviance Table (Type II Tests) of the four GLMs for the endemic plant species. Analysed were the influence of recorded fitness parameters on *Biscutella laevigata* ssp. *austriaca, Galium truniacum, Hieracium porrifolium* and *Cerastium carinthiacum* ssp. *carinthiacum*. The factors for the significant variables of each model or the variables that best explain the model are listed.

		Chisq	**Df**	**Pr(>Chisq)**
Biscutella laevigata ssp. *austriaca*	MASL	17.855	1	2.384e-05
Galium truniacum	Exposure	52.006	3	0.0002613
	Coarse.debris	19.100	1	0.0054477
Hieracium porrifolium	Exposure	12.3143	3	0.0001028
	Block.debris	2.4042	1	0.0303369
Cerastium carinthiacum ssp. *carinthiacum*	MASL	7.8157	1	0.005179
	Fine.debris	2.3219	1	0.127562 (not significant)

Table A.4 List of calculated percentages of plots categorised as A, B and C in terms of degree of preservation. The categorised transects were aggregated and then the percentage for each factor was calculated for each slope, divided into the influencing classifications A, B and C.

	Haindlkar	**Gseng**	**Langgries**	**Kühgraben**
Neighbouring biotopes (NB)	A: 96 % B: 4 % C: 0 %	A: 100 % B: 0 % C: 0%	A: 100 % B: 0 % C: 0 %	A: 100 % B: 0 % C: 0 %
Anthropogenic Influence (AnI)	A: 92 % B: 8 % C: 0 %	A: 71 % B: 29 % C: 0 %	A: 100 % B: 0 % C: 0 %	A: 46 % B: 50 % C: 4 %
Invasive and impairing species and neophytes (InN)	A: 100 % B: 0 % C: 0 %	A: 76 % B: 24 % C: 0 %	A: 100 % B: 0 % C: 0 %	A: 100 % B: 0 % C: 0 %

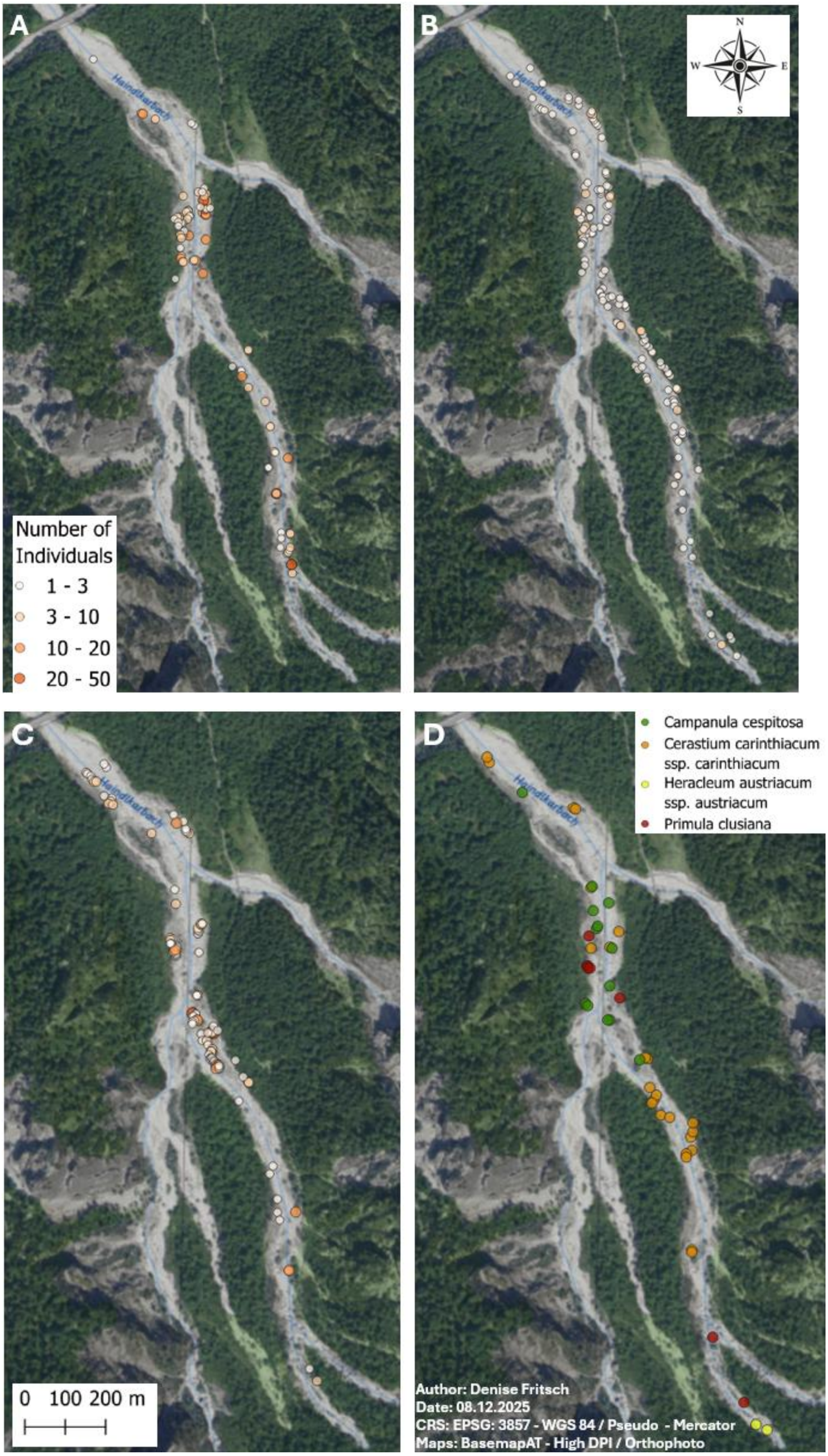

***Figure A.5** Maps showing the distribution of endemic plants on the **Haindlkar**.* Biscutella laevigata *ssp.* austriaca *(A)*, Galium truniacum *(B) and* Hieracium porrifolium *(C) are represented by points indicating the number of individuals. For the remaining species (D), one point counts as one individual. Maps were created using QGIS version 3.24.12.*

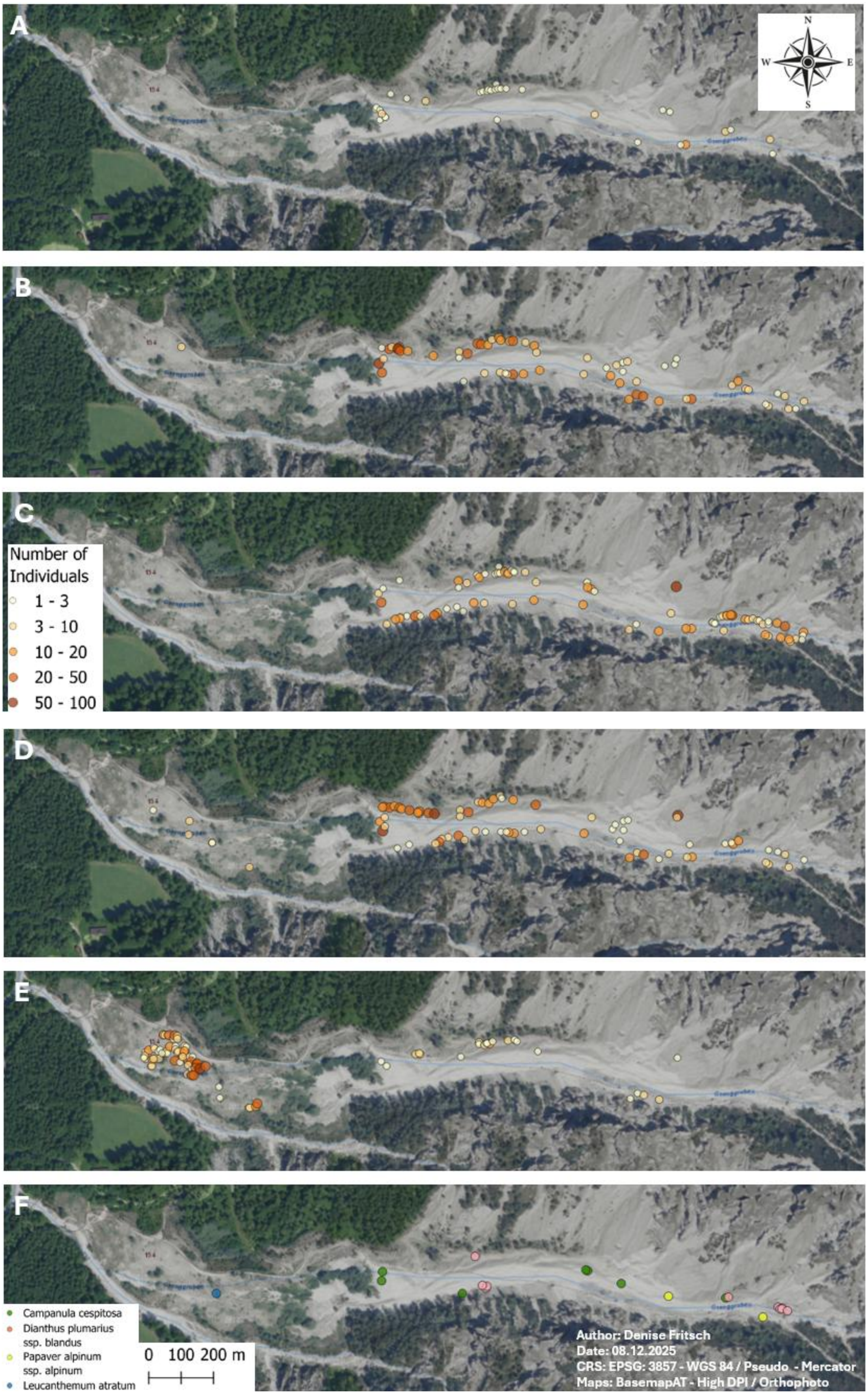

Figure A.6 *Maps showing the distribution of endemic plants on the* ***Gseng****.* Asperula neilreichii *(A)*, Biscutella laevigata *ssp.* austriaca *(B)*, Cerastium carinthiacum *ssp.* carinthiacum *(C)*, Galium truniacum *(D) and* Hieracium porrifolium *(E) are represented by points indicating the number of individuals. For the remaining species (F), one point counts as one individual. Maps were created using QGIS version 3.34.12.*

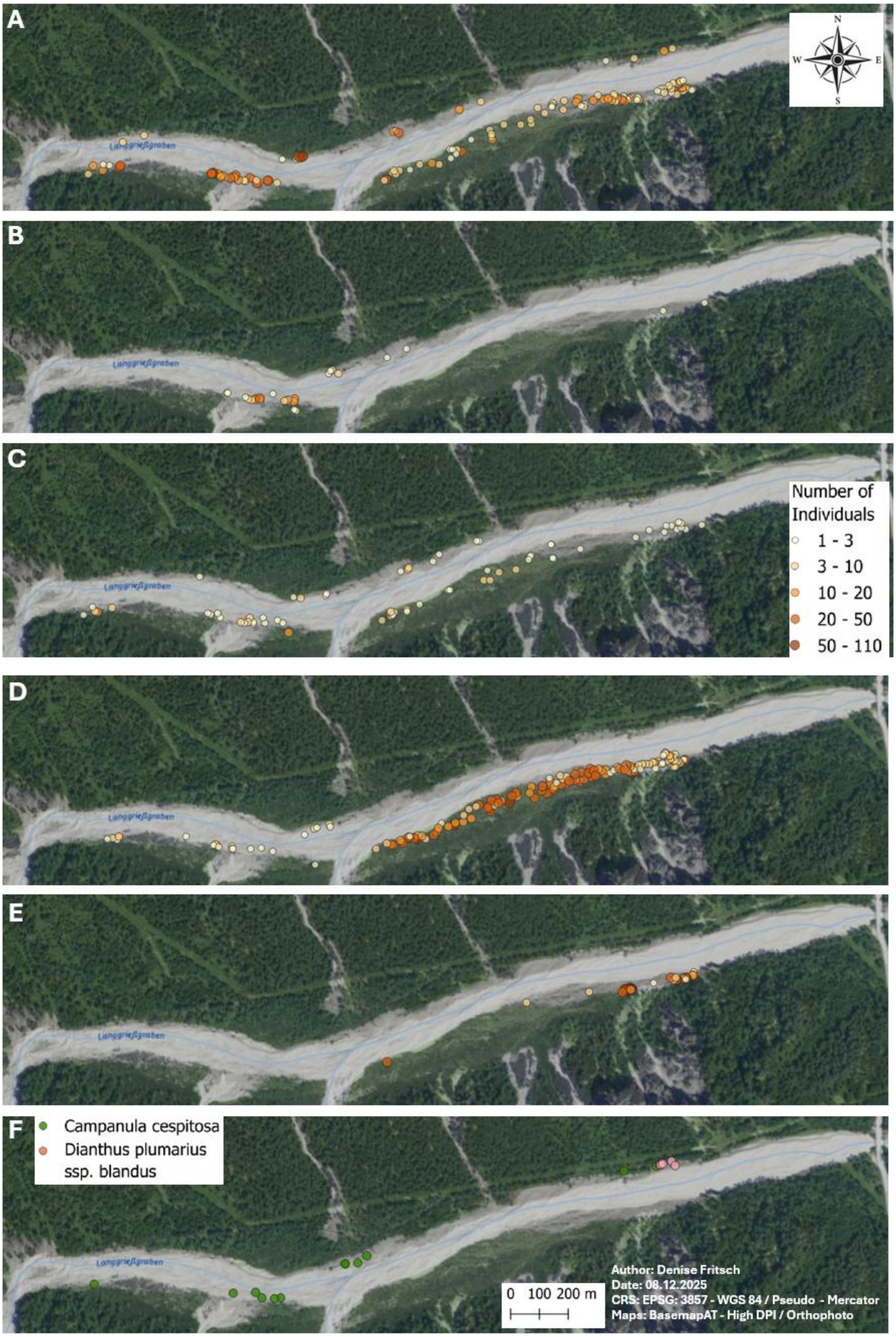

Figure A.7 *Maps showing the distribution of endemic plants on the* ***Langgries****.* Biscutella laevigata *ssp.* austriaca *(A)*, Cerastium carinthiacum *ssp.* carinthiacum *(B)*, Galium truniacum *(C),* Hieracium porrifolium *(D) and* Primula clusiana *(E) are represented by points indicating the number of individuals. For the remaining species (F), one point counts as one individual. Maps were created using QGIS version 3.34.12.*

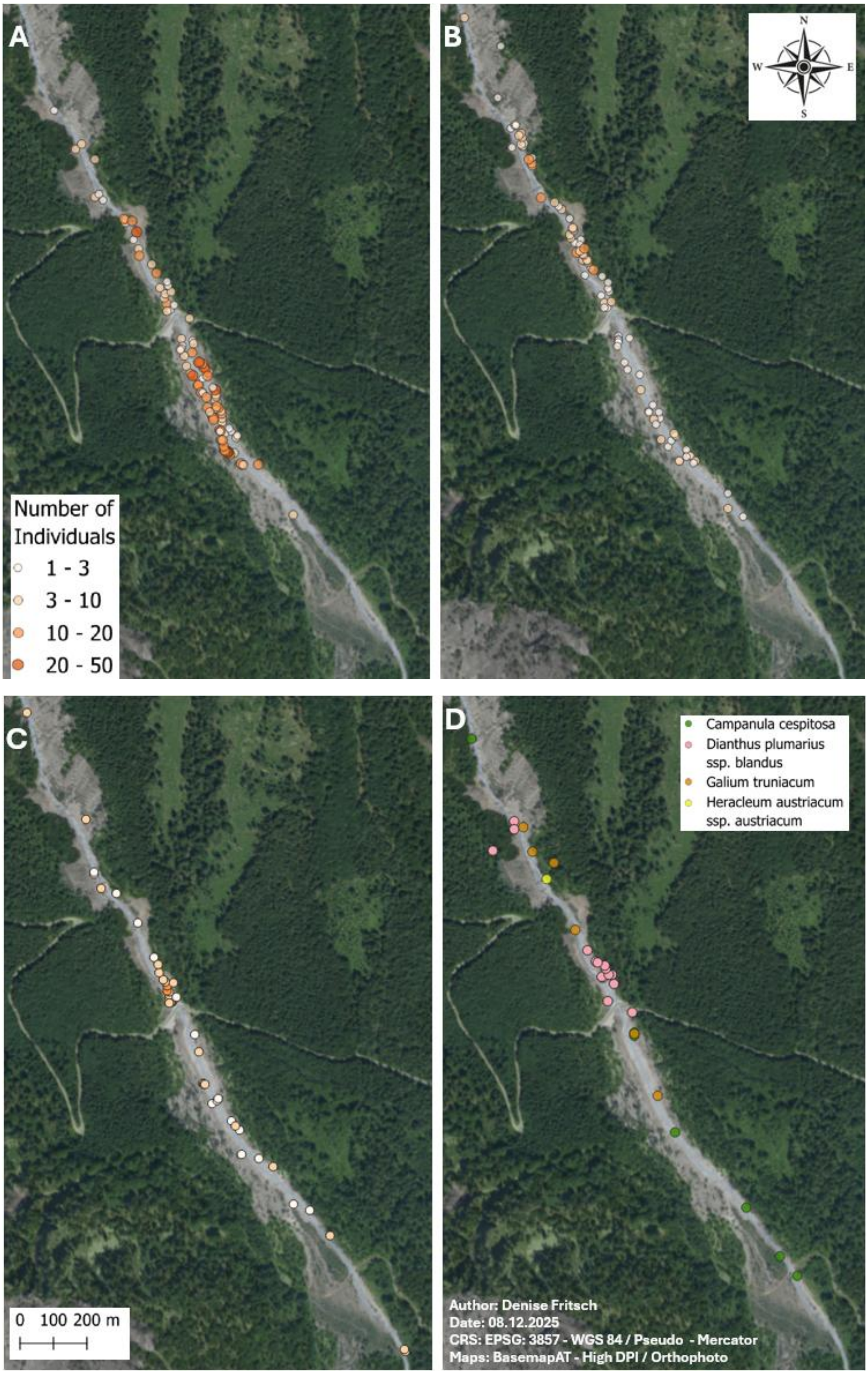

Figure A.8** Maps showing the distribution of endemic plants on the **Kühgraben. Biscutella laevigata *ssp.* austriaca *(A)*, Cerastium carinthiacum *ssp.* carinthiacum *(B) and* Hieracium porrifolium *(C) are represented by points indicating the number of individuals. For the remaining species (D), one point counts as one individual. Maps were created using QGIS version 3.34.12.*

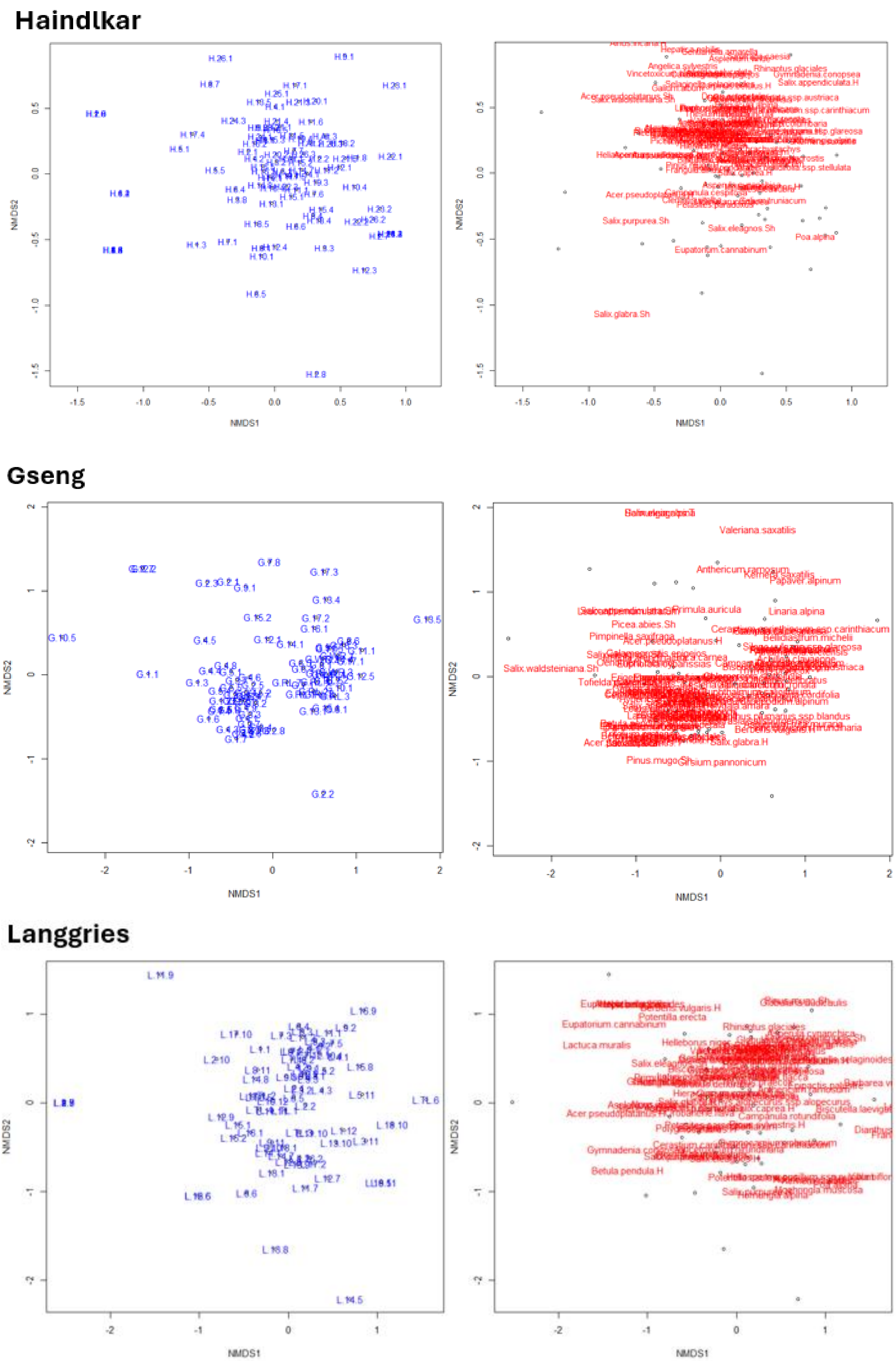

Figure A.9 *Ordination diagrams of Haindlkar, Gseng and Langgries. Plots are displayed on the left; species are displayed on the right.*

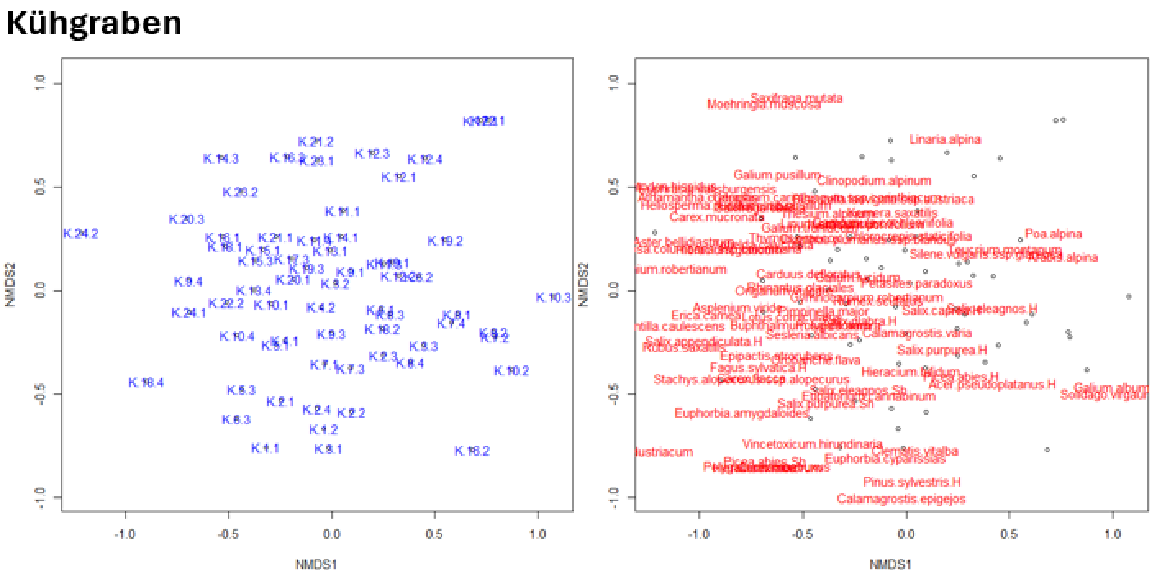

__Figure A.10__ Ordination diagrams of the Kühgraben. Plots are displayed on the left; species are displayed on the right.

8 Declaration

Use of AI-based applications

AI-applications were used in the course of this thesis, specifically Open AI (ChatGPT). The use of this AI has been limited exclusively to improving existing code in R and improving the vocabulary of this thesis by suggesting synonyms and stylistic alternatives.

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