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Identification of regional chorotypes of vascular plants by means of hierarchical cluster analysis based on Floristic Mapping of Austria

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Abstract: This study aims to identify regional chorotypes (floristic elements) of the vascular flora of Austria using quantitative methods. The analysis is based on more than 2 million validated observation records of the project "Floristic Mapping of Austria" and was performed by hierarchical cluster analysis. Species of similar distribution were grouped into clusters and for each cluster of similar species, the main area of distribution was identified and the binding degree of each assigned species was evaluated. A subsequent characterisation of the revealed regional chorotypes was performed by calculating statistical key figures and other parameters. At the cutlevel of 30 identified clusters, the assigned species of 24 clusters showed a satisfactory degree of binding to the clusters. The chorotypes are presented and visualised.

Key words: vascular flora of Austria; identification of regional chorotypes; distribution patterns; floristic elements; hierarchical cluster analysis; Floristic Mapping of Austria

Zusammenfassung: **Identifizierung von regionalen Arealtypen der Gefäßpflanzen mittels hierarchischer Clusteranalyse auf Grundlage der Floristischen Kartierung Österreichs**
Das Ziel dieser Studie ist die Identifizierung von regionalen Arealtypen der Gefäßpflanzenflora Österreichs mittels quantitativer Methoden. Die Analyse basiert auf über 2 Millionen validierten Kartierungsangaben der „Floristischen Kartierung Österreichs" und wurde mittels hierarchischer Clusteranalyse durchgeführt. In ihrer Verbreitung ähnliche Arten wurden zu Clustern gruppiert. Es wurde der Verbreitungsschwerpunkt jedes Clusters identifiziert und es wurde der Bindungsgrad aller zum Cluster zugewiesenen Arten berechnet. Eine darauffolgende Charakterisierung der so ermittelten regionalen Arealtypen erfolgte mittels statistischer Kennzahlen und anderer Parameter. Bei einem Cutlevel von 30 identifizierten Clustern zeigten die Arten von 24 Clustern einen zufriedenstellenden Bindungsgrad an den jeweiligen Cluster. Die solcherart identifizierten Arealtypen werden vorgestellt und visualisiert.

Introduction

In floristic plant geography, the identification of floristic regions and floristic elements (or chorotypes) is a major objective (McLaughlin 1994). In biogeography, the terms "floristic element" and also "chorotype" have different meanings. In this study, the use of the term "regional chorotype" follows the proposal of S. Fattorini and indicates a group of species with similar distributions within a certain region (Fattorini 2015).

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Previously, the identification of chorotypes was done manually by comparing and grouping distribution maps based on their similarity. In the 1970s, H. Haeupler calculated the similarity of occurrences between species utilizing the chi-square method and presented the result in a constellation diagram and a dendrogram (Haeupler 1974). Birks (1976) delimited floristic regions and floristic elements by ordination (principal component analysis) and minimum-variance cluster analysis with a modified Jaccard's coefficient as dissimilarity measurement based on distribution data in a 5° latitude and 6° longitude grid reference system of 144 European pteridophyte species. Poldini & Martini (1995) carried out a typification of distribution patterns using quantitative analyses in north-eastern Italy. Finnie & al. (2007) identified floristic elements in the European vascular flora based on data derived from the "Atlas Florae Europaeae", using a 50 × 50 km UTM grid system, of approximately 2,800 species. The clusters of species were identified by complete linkage clustering and the Jaccard's coefficient as similarity measurement. Small clusters were eliminated by forcing them to link with bigger clusters and reallocation of the species to the redefined clusters. Wasowicz & al. (2014) analysed the distribution patterns of vascular plants native to Iceland in a 10 × 10 km reference grid system based on approximately 500,000 floristic observation records. The clusters were calculated with the statistical programme Spherikm (available from https://www.brc.ac.uk/biblio/spherikm-computer-program-clustering-columns-and-rows-occurrence-matrix-using-weighted), which uses spherical k-means clustering (Hill & al. 2013). Preston & al. (2011, 2013a) identified the distribution patterns of British and Irish liverworts, hornworts, and mosses and followed the methods of Finnie & al. (2007). Preston & al. (2013b) also classified distribution patterns of the British and Irish vascular flora on a 10 km square scale based on 1,405 species and 1,510,290 observation records by perpendicular spherical k-means clustering as implemented in Spherikm. Gatto & Cohn-Haft (2021) used spatial analyses for the identification of chorotypes and proposed spatial congruence analysis (SCAN), which is based on polygons (shape files) rather than on grid cells as species range maps.

Further methods have been used for pattern recognition in biogeographical data. For example, Vilhena & Antonelli (2015) used network clustering to reveal biogeographical regions and compared the results with a similarity approach (β-similarity, UPGMA cluster method). NAM (network analysis method) was used to analyse sympatry networks (Dos Santos & al. 2008, 2012) and areas of endemism (Torres-Miranda & al. 2013). C. Szumik and colleagues determined areas of endemism based on an optimality criterion (Szumik & al. 2002, Szumik & Goloboff 2004).

Hitherto, typification of chorotypes of the vascular plant flora in Austria was based on expert judgement. A first quantitative identification of regional chorotypes of the vascular plant flora of Austria based on data from the "Floristic Mapping of Austria" was performed in 2020 (Billensteiner 2020) by means of hierarchical cluster analysis with subsequent assessment of the clusters and is repeated in the present study with an enhanced and updated data set. The recognized chorotypes will be presented and characterized.

Data and Methods

Biogeographical analysis requires reliable distribution data. The current study is based on the data of the "Floristic Mapping of Austria". This project aims to comprehensively record vascular plants in Austria (Niklfeld & al. 2008, 2021) and was initiated by F. Ehrendorfer and U. Hamann in the 1960s (Ehrendorfer & Hamann 1965). It is embedded in a Central European framework and is based on grid cells (3′ longitude, 5′ latitude, average area of 35 km²) as a topographic reference unit (Niklfeld 1971, 1997). The analysis included all native (incl. archaeophytic) species that are recorded from at least 1% of all grid cells in Austria (at least 26 grid cells). Thus, more than 2 million validated observation records of 1,932 vascular plant species (infraspecifica taxa were merged into the respective species) were included in this investigation (data as of January 2021).

The taxonomy and nomenclature follow the checklist "Liste der Gefäßpflanzen Österreichs" (Ehrendorfer 1967, Gutermann & Niklfeld 1973) and later revisions (Gilli & al. 2019).

Based on the observation records, the distribution of each species was determined (presence/absence in grid cells). To recognize regional chorotypes, species with similar distributions were grouped into clusters. For this purpose a hierarchical agglomerative cluster analysis with the statistical software R (R Core Team 2021) was performed using the fastcluster package (Müllner 2013). As cluster algorithm, the Ward method (minimum-variance method) was applied by using Euclidean distance as similarity measurement. For comparison, the complete linkage method (furthest-neighbour method) was applied to the same dataset by using the Dice index (Sørenson index), the Jaccard index, and the Euclidean distance (Johnston 1976, Bacher & al. 2010).

The main area of distribution was calculated for each cluster: In a first step the cell(s) with the most species (n_{max}) were identified. In a second step the main area of distribution of a cluster was defined as the set of all grid cells that harbour at least 50% of the species found in the n_{max} cell.

Subsequently, a binding degree f_{link} was calculated for all 1,932 species to indicate how strongly a species is linked to a cluster. The regional chorotype is defined as the group of species with binding degree f_{link} of at least 50 and is visualised as map.

The binding degree f_{link} is defined as follows:

$$f_{\text{link}} = \frac{p_{\text{tax}} \cdot p_{\text{main}}}{100}$$

$$p_{\text{tax}} = \frac{cnt_{\text{taxmain}}}{cnt_{\text{tax}}}$$

$$p_{\text{main}} = \frac{cnt_{\text{taxmain}}}{cnt_{\text{main}}}$$

f_{link}	Binding degree of species X to a cluster (scale from 0 to 100).
p_{tax}	Percentage of grid cells occupied by species X that belong to the main area of the cluster compared to the total distribution of the species in Austria.
p_{main}	Percentage of grid cells occupied by species X that belong to the main area of the cluster compared to the total number of grid cells in the main distribution area.
$cnt_{taxmain}$	Number of grid cells occupied by species X that belong to the main area of the cluster.
cnt_{tax}	Number of grid cells occupied by species X in Austria, i. e. the total distribution of the species in Austria.
cnt_{main}	Number of grid cells in main distribution area of the cluster.

The following parameters ("key figures") are used for the characterisation of the clusters:

Number of species	Total number of species assigned to a cluster.
Maximum b. d. of species	Maximum binding degree (b. d.) of the species assigned to a cluster.
Minimum b. d. of species	Minimum binding degree of the species assigned to a cluster.
Average b. d. of species	Average binding degree of the species assigned to a cluster.
Standard deviation b. d. of species	Standard deviation of binding degree of the species assigned to a cluster.
Number of grid cells	Number of grid cells with at least one species assigned to a cluster.
Number of grid cells in main area	Number of grid cells in main area of a cluster.
Number of species (b. d. ≥ 50) in main area	Number of species with binding degree of at least 50 in main area of a cluster.
Percentage of species b. d. ≥ 50	Percentage of species with binding degree of at least 50 of a cluster.

The parameter "overall assessment" (*oa*) of a cluster takes the following figures into account: percentage of species of a cluster with a minimum binding degree of 50 (ps_{50}), the maximum ($cf_{\max}$) and the average (cf_{avg}) binding degree of the species assigned to a cluster. This parameter has a scale from 0 to 100 and is calculated as the mean of these three values:

$$oa = (cf_{\max} + cf_{\text{avg}} + ps_{50}) / 3$$

For each regional chorotype, the main areas, the main altitudinal zones and the characteristic habitats were determined based on the distribution of the species by bibliographical references (Niklfeld 1973, 1979, 2013, Bobek 1975, Meusel & al. 1978, Sauberer & Grabherr 1995a, 1995b, Ellenberg 1996, Wilmanns 1998, Borsdorf 2005, Moser & al. 2005, Fischer & al. 2008, Sauberer & al. 2017, Müller & al. 2021), topographical and geological maps and literature (Geologische Bundesanstalt 2013, Schuster 2015, Brüggemann-Ledolter & al. 2018, Linner & al. 2018, Bundesamt für Eich- und Vermessungswesen 2024).

The comparison of the clustering methods and similarity measurements was mainly done based on the binding degree of the species. The best clustering method and similarity index is the one with the largest number of species assigned to a cluster with a binding degree of at least 50.

To test the stability of the recognized regional chorotypes, the cluster analysis was repeated with a reduced data set. Only native species with a distribution in at least 5% of the grid cells (at least 130 grid cells) were included, which resulted in a reduced dataset of 1,367 species (71%). It was verified, that this change in the input dataset does not have a massive impact on the result (Bacher & al. 2010).

Results and Discussion

Different cluster methods and distance measures resulted in quite similar chorotypes, nevertheless, the comparison of the assigned species and the binding degrees proved the better suitability of the Ward method than the complete linkage method, as most species with a binding degree of at least 50 were provided by the Ward method in combination with the Euclidean distance. The better performance of the Ward method was also observed for biogeographical regionalisation on the same dataset (Billensteiner & Niklfeld 2021) and different datasets by H. Kreft and W. Jetz, who compared ordination, different clustering methods and similarity measures with the aim of identifying biogeographical regions (Kreft & Jetz 2010). Subsequently, the results of the Ward method are described.

At cutlevel 30, 601 of 1,932 species were assigned to clusters with a binding degree of at least 50 (see electronic supplement: Fig. S1). The clusters were relatively equally sized apart from 3 clusters, to which many species with a low binding degree were assigned (see electronic supplement: Fig. S2). At cutlevel 30, 24 clusters contained species with a minimum binding degree of 50. For 6 clusters no species with a binding larger than 50 could be found.

Stability tests, which were carried out on a reduced set of data with 71% of the species, provided satisfying results. At cutlevel 30, 27 regional chorotypes (visualised as map) were matching, and 536 of 601 species with a minimum binding degree of 50 were assigned to the same cluster.

The results were compared with the former master thesis (Billensteiner 2020), which was based on fewer floristic observation records (data as of December 2017). At cutlevel 30, 26 regional chorotypes were matching and out of the matching chorotypes, 73% of the species with a minimum binding degree of 50 were assigned to the same cluster. The concordance increases with the binding degree. For example, 85% of the species were assigned to the same cluster, if considering species with a minimum binding degree of 75.

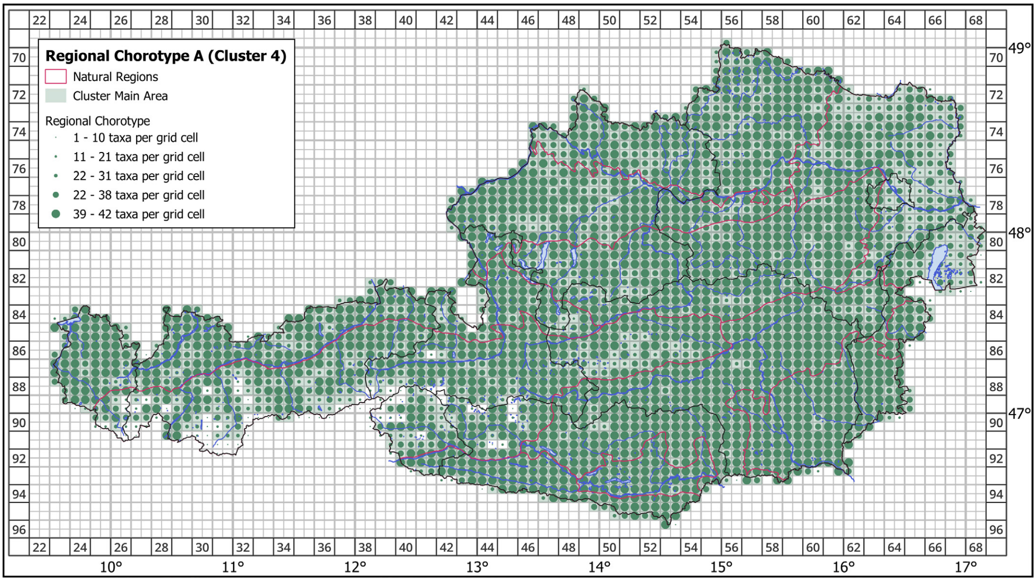
Plate 1 to Plate 19 visualise and describe the cluster main areas, the resulting regional chorotypes and the cluster key figures at cutlevel 30 with an overall assessment of at least 40 scores by using the Ward method in combination with the Euclidean distance. The maps of the regional chorotypes are presented as cumulative distribution maps of the assigned species. The natural regions are outlined according to the natural landscape classification of Austria by Sauberer & Grabherr (1995a). The main altitudinal zones are marked with dark blue arrows in the section "Altitude", whereas light blue arrows indicate zones with less frequent occurrences.

Regional chorotype A (Plate 1) includes common species that are widely distributed in Austria. Many of these species occur in ruderal or otherwise anthropogenically influenced habitats. Widely distributed and common species from the colline to the montane zone are assigned to chorotype B (Plate 2), whereas chorotype C (Plate 3) includes common species of various habitats from the colline to the subalpine zone. Many species of chorotype D (Plate 4) are calcicolous, distributed from the colline to the montane zone of the Northern and the Southern Calcareous Alps, the Klagenfurt Basin, the eastern Waldviertel (most eastern part of the Northern Granite and Gneiss Highland) and other regions to a lower extent. Chorotype E (Plate 5) includes substrate-indifferent species of various habitats with main distribution area in all ranges of the Alps, whereas species of moist to wet, mostly acid habitats from the submontane to the subalpine zone are assigned to chorotype F (Plate 6). The main distribution of chorotype G (Plate 7) is the subalpine to alpine zone. The assigned species occur on various substrates and have various moisture requirements. Chorotype H (Plate 8) includes species of primary grasslands over calcareous bedrock, scree vegetation, nutrient-poor grassland and snowbed communities from the subalpine to the alpine and partly subnival zone. Species of mostly acid habitats in the Central Alps are assigned to chorotype I (Plate 9), with main distribution from the subalpine to the alpine zone, and to chorotype J (Plate 10) with main distribution in the alpine to partly the subnival zone. The main areas of chorotype K (Plate 11) are the Northern and Southern Alps from the montane to the alpine zone, and the assigned species are specific to calcareous bedrock. Species of chorotype L (Plate 12) are mainly distributed in the Northern and Southern Alps as well. They are calcicolous and are distributed mainly in the montane to subalpine zone, but compared to chorotype D only to a lower extent in the colline and the submontane zone. Chorotype M (Plate 13) includes many ruderal species that are widely distributed from the planar-colline to montane zone like in the Prealpine Forelands, Klagenfurt Basin, Pannonian region and mainly the eastern part of the Northern Granite and Gneiss Highland. Species assigned to chorotype N (Plate 14) are mainly distributed in the planar-colline to montane zone in the Prealpine Forelands, in the Klagenfurt Basin and in the Pannonian region, but less present in the Northern Granite and Gneiss Highland except for the easternmost part. Species of chorotype O (Plate 15) are mostly calcifuges, distributed from the colline to montane zone of the Prealpine Forelands, the Klagenfurt Basin and the Northern Granite and Gneiss Highland. The main area of chorotype P (Plate 16) is the Prealpine Foreland, the Klagenfurt Basin and the Pannonian plains. The species are distributed mainly in the planar-colline zone, often in anthropogenic habitats, reaching into the montane belt. Species of chorotype Q (Plate 17) are distributed from the planar-colline to montane zone, often in more or less calcareous habitats in the Calcareous Alps, in parts of the Forelands, the Pannonian region and the easternmost part of the Northern Granite and Gneiss Highland. The main area of chorotype R (Plate 18) is the colline to montane zone of the Calcareous Alps, parts of the Forelands, and easternmost part of the Northern Granite and Gneiss Highland on the border to the Pannonian region. Out of the presented chorotypes, the cluster of chorotype R has the lowest overall assessment. However, this chorotype includes species that mainly occur over limestone in deciduous forests (“Edellaubwälder”), indicating nutrient-rich and calcareous soils. Chorotype S (Plate 19) includes thermophilic species adapted to the Pannonian climate. The main areas are the Pannonian region and surroundings, including the Danube Valley up to Linz.

Conclusions

As a matter of fact, hierarchical cluster analysis groups all species based on their distribution into a predefined number of clusters. Therefore, a subsequent assessment of the assigned species with a binding degree to the cluster is necessary. When carrying out manual classification by comparing and grouping distribution maps based on their similarity a residual set of apparently indifferently distributed species remains. With this statistical approach, a residual number of species with a low binding degree is left over. The binding degree of species to the recognized cluster increases with the number of clusters, therefore a further analysis with an increased number of clusters would result in more chorotypes of higher binding degrees. The cumulative distribution maps of the regional chorotypes and the main areas of the clusters coincide, which confirms the suitability of the assessment method of the assigned species by binding degree.

Regional Chorotype A (Cluster 4): Widely distributed

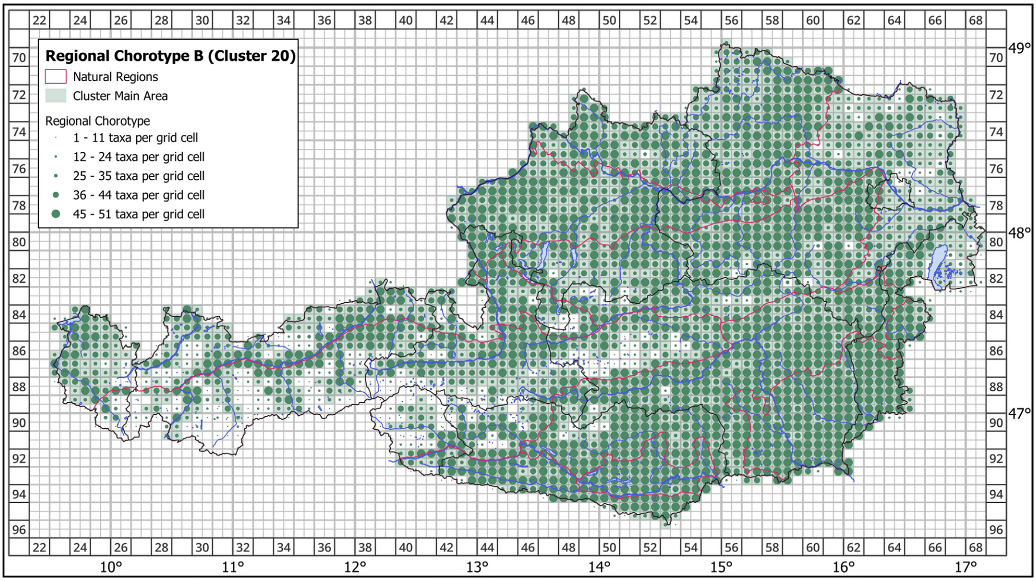


Altitude	Cluster key figures		Ranking by binding degree (b. d.)	
subnival	Number of species	42	*Plantago major*	98
alpine	Maximum b. d. of species	98	*Urtica dioica*	97
subalpine	Minimum b. d. of species	86	*Trifolium repens*	97
montane	Average b. d. of species	93	*Ranunculus repens*	97
submont.	Standard deviation b. d. of species	3.3	*Trifolium pratense*	97
colline	Number of grid cells	2589	*Plantago lanceolata*	97
planar	Number of grid cells in main area	2495	*Heracleum sphondylium*	96
	Number of species in main area	42	*Tussilago farfara*	96
	Percentage of species b. d. >= 50	100%	*Equisetum arvense*	96
	Overall assessment	97	*Cirsium arvense*	96

Regions	Habitat / Comments
Widely distributed in Austria, but less present in the glacial regions and very high regions of Ötztal Alps, Stubai Alps, Zillertal Alps, Hohe Tauern, Niedere Tauern.	Common species in Austria, many of them occurring in ruderal or otherwise anthropogenically influenced habitats.

Plate 1: Regional Chorotype A: Map and characteristics. — **Tafel 1:** Regionaler Arealtyp A: Kartendarstellung und Kenndaten.

Regional Chorotype B (Cluster 20): From colline to montane

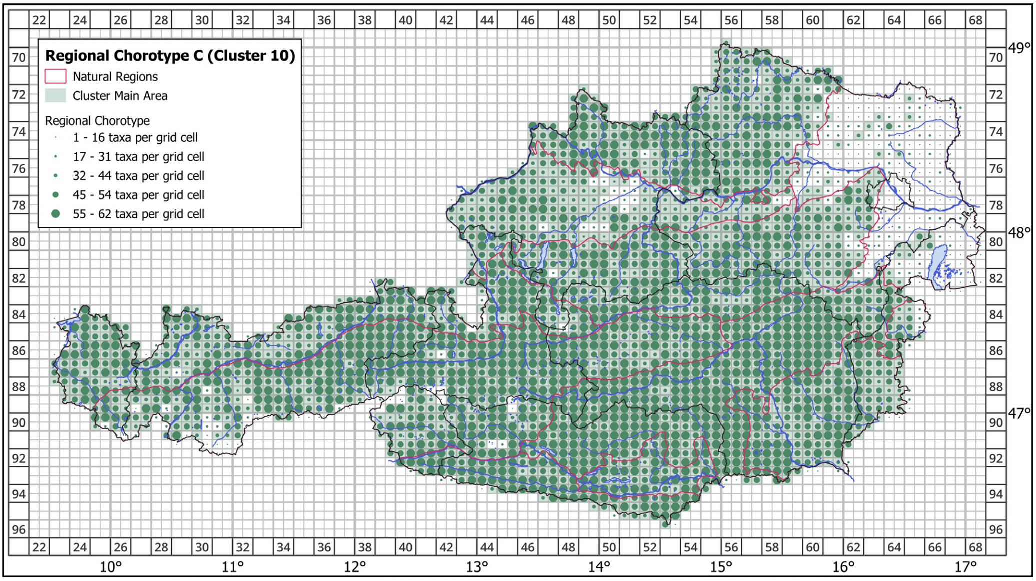


Altitude	Cluster key figures		Ranking by binding degree (b. d.)	
subnival	Number of species	51	*Arrhenatherum elatius*	93
alpine	Maximum b. d. of species	93	*Fraxinus excelsior*	92
subalpine	Minimum b. d. of species	67	*Corylus avellana*	91
montane	Average b. d. of species	82	*Sambucus nigra*	91
submont.	Standard deviation b. d. of species	6.0	*Scrophularia nodosa*	91
colline	Number of grid cells	2541	*Geum urbanum*	90
planar	Number of grid cells in main area	2231	*Hypericum perforatum*	89
	Number of species in main area	51	*Crepis biennis*	89
	Percentage of species b. d. >= 50	100%	*Knautia arvensis* s. str.	88
	Overall assessment	92	*Rumex acetosa*	88

Regions	Habitat / Comments
From colline to montane zone in all regions, fewer species in the lowlands of the Pannonian region, but common in the higher Pannonian regions like Leithagebirge and Leiser Berge.	Widely distributed and common species, various habitats like moist, nutrient-rich deciduous forests, ruderal shrubs, fertilized meadows, waysides, many nitrophilous species like *Sambucus nigra*.

Plate 2: Regional Chorotype B: Map and characteristics. — **Tafel 2:** Regionaler Arealtyp B: Kartendarstellung und Kenndaten.

Regional Chorotype C (Cluster 10): From colline to subalpine

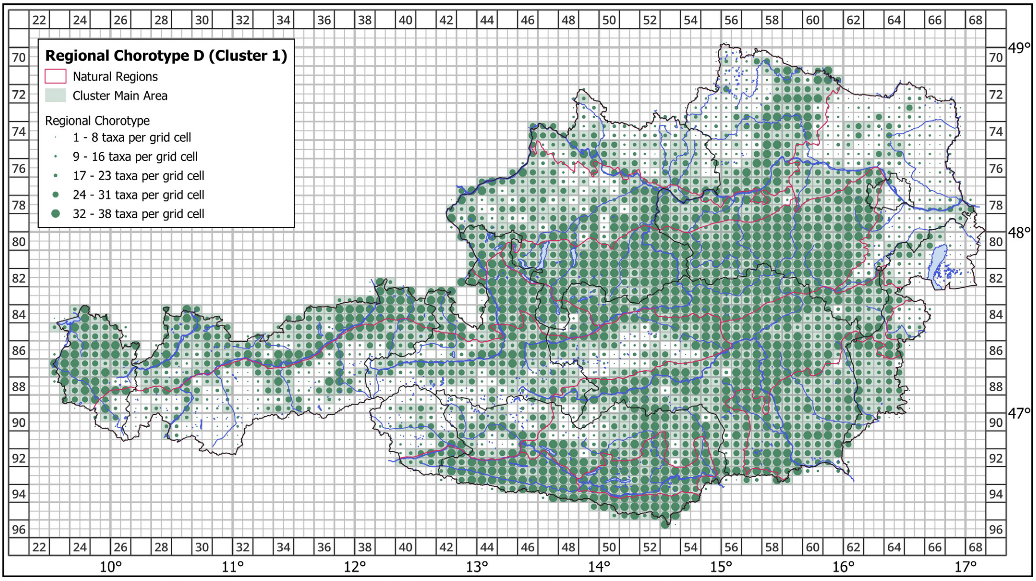


Altitude	Cluster key figures		Ranking by binding degree (b. d.)	
subnival	Number of species	62	*Oxalis acetosella*	95
alpine	Maximum b. d. of species	95	*Athyrium filix-femina*	94
subalpine	Minimum b. d. of species	58	*Rubus idaeus*	94
montane	Average b. d. of species	82	*Potentilla erecta*	94
submont.	Standard deviation b. d. of species	8.4	*Hieracium murorum*	92
colline	Number of grid cells	2581	*Sorbus aucuparia*	92
planar	Number of grid cells in main area	2211	*Vaccinium myrtillus*	92
	Number of species in main area	62	*Epilobium montanum*	91
	Percentage of species b. d. >= 50	100%	*Fragaria vesca*	90
	Overall assessment	92	*Maianthemum bifolium*	90

Regions	Habitat / Comments
From colline to subalpine zone in all regions, except the lowlands of the Pannonian Plains, or only in the highest, submontane regions like Leithagebirge and Leiser Berge. Compared to chorotype M also occurring in the higher regions of the Central Alps.	Common species of various habitats, e.g. *Rubus idaeus* as indicator for nitrification or *Potentilla erecta* as a low-nutrient indicator.

Plate 3: Regional Chorotype C: Map and characteristics. — **Tafel 3:** Regionaler Arealtyp C: Kartendarstellung und Kenndaten.

Regional Chorotype D (Cluster 1): Calcareous Alps, Klagenfurt Basin, parts of the Forelands and eastern Waldviertel – from colline to montane (subalpine)

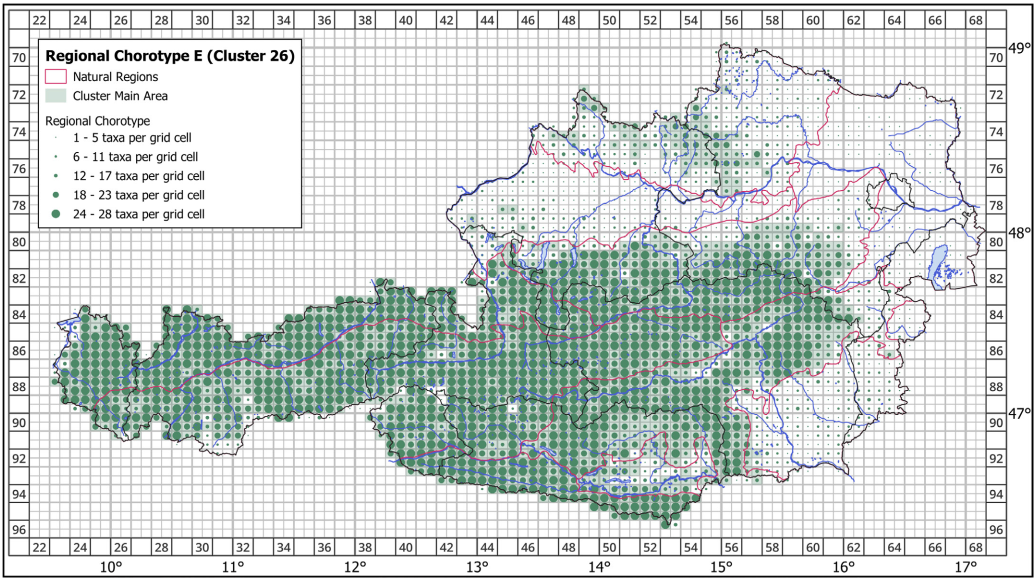


Altitude	Cluster key figures		Ranking by binding degree (b. d.)	
subnival	Number of species	38	*Paris quadrifolia*	80
alpine	Maximum b. d. of species	80	*Salvia glutinosa*	80
subalpine	Minimum b. d. of species	58	*Actaea spicata*	79
montane	Average b. d. of species	70	*Fagus sylvatica*	78
submont.	Standard deviation b. d. of species	6.0	*Melica nutans* s. str.	76
colline	Number of grid cells	2549	*Daphne mezereum*	76
planar	Number of grid cells in main area	1879	*Origanum vulgare* s. str.	75
	Number of species in main area	38	*Petasites hybridus*	75
	Percentage of species b. d. >= 50	100%	*Alnus incana*	75
	Overall assessment	83	*Mercurialis perennis* s. str.	75

Regions	Habitat / Comments
Main area from the colline to the montane zone of the Northern and Southern Calcareous Alps, in the Klagenfurt Basin, in the lower-mountain part of the Central Alps and the eastern Waldviertel (most eastern part of the Northern Granite and Gneiss Highland); to a lower extent in the Southeastern Prealpine Foreland. In the Pannonian region only in the highest parts (as in chorotype C).	Many species are calcicoles and occur in deciduous forests or clearings over limestone.

Plate 4: Regional Chorotype D: Map and characteristics. — **Tafel 4:** Regionaler Arealtyp D: Kartendarstellung und Kenndaten.

Regional Chorotype E (Cluster 26): Alps – from submontane to alpine

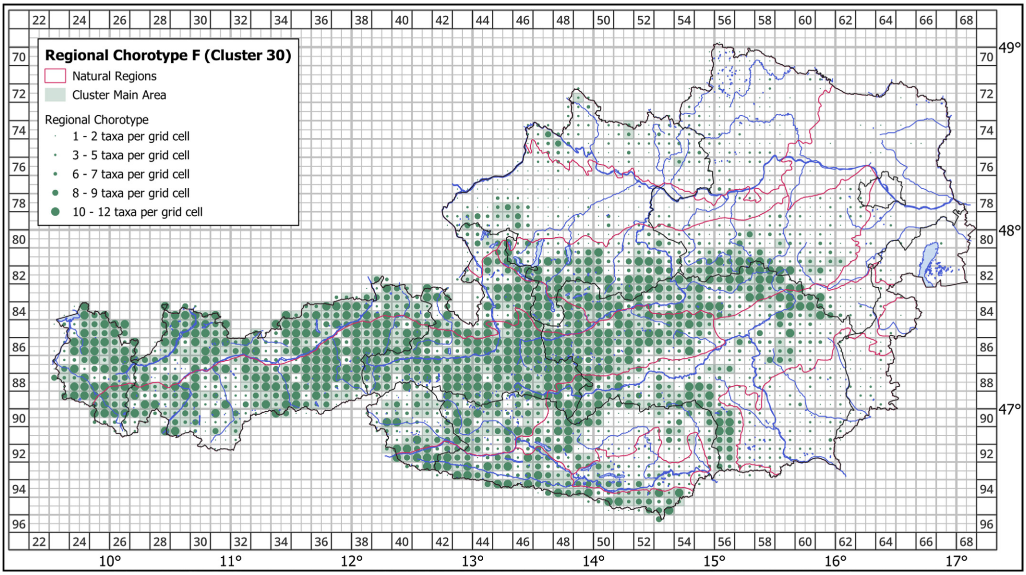


Altitude	Cluster key figures		Ranking by binding degree (b. d.)	
subnival	Number of species	28	*Salix appendiculata* s. str.	84
alpine	Maximum b. d. of species	84	*Homogyne alpina*	83
subalpine	Minimum b. d. of species	61	*Larix decidua*	82
montane	Average b. d. of species	73	*Vaccinium vitis-idaea*	81
submont.	Standard deviation b. d. of species	5.9	*Melampyrum sylvaticum* s. str.	80
colline	Number of grid cells	2401	*Polygonatum verticillatum*	79
planar	Number of grid cells in main area	1507	*Parnassia palustris*	77
	Number of species in main area	28	*Gymnocarpium dryopteris*	76
	Percentage of species b. d. >= 50	100%	*Lycopodium annotinum*	74
	Overall assessment	86	*Rosa pendulina*	74

Regions	Habitat / Comments
Distributed mainly in the Alps, some species are also distributed in the higher and therefore cooler regions of the Northern Granite and Gneiss Highland.	Substrate indifferent, but often preferring acidic soils, various habitats.

Plate 5: Regional Chorotype E: Map and characteristics. — **Tafel 5:** Regionaler Arealtyp E: Kartendarstellung und Kenndaten.

Regional Chorotype F (Cluster 30): Alps – from submontane to subalpine

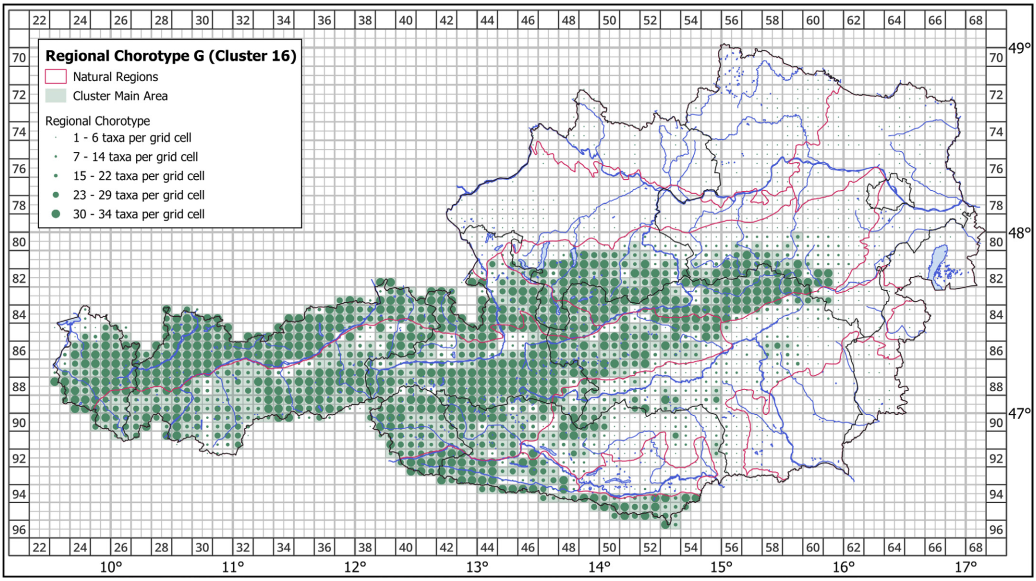


Altitude	Cluster key figures		Ranking by binding degree (b. d.)	
subnival	Number of species	28	*Luzula luzulina*	60
alpine	Maximum b. d. of species	60	*Pinguicula vulgaris*	58
subalpine	Minimum b. d. of species	34	*Willemetia stipitata*	57
montane	Average b. d. of species	47	*Carex flava* s. str.	56
submont.	Standard deviation b. d. of species	7.5	*Blechnum spicant*	55
colline	Number of grid cells	2313	*Thelypteris limbosperma*	55
planar	Number of grid cells in main area	958	*Moneses uniflora*	55
	Number of species in main area	12	*Carex davalliana*	54
	Percentage of species b. d. >= 50	43%	*Lactuca alpina*	53
	Overall assessment	50	*Carex echinata*	51

Regions	Habitat / Comments
Distributed mainly in the Alps. Highest number of species per grid cell in parts of the Central Alps. Most species are less present in the Northern Granite and Gneiss Highland.	Moist to wet, mostly acidic habitats like forests on acidic soils, marshy meadows, fens, and spring mires. Few calcicoles like *Carex davalliana*.

Plate 6: Regional Chorotype F: Map and characteristics. — **Tafel 6:** Regionaler Arealtyp F: Kartendarstellung und Kenndaten.

Regional Chorotype G (Cluster 16): Alps – from (montane) subalpine to alpine

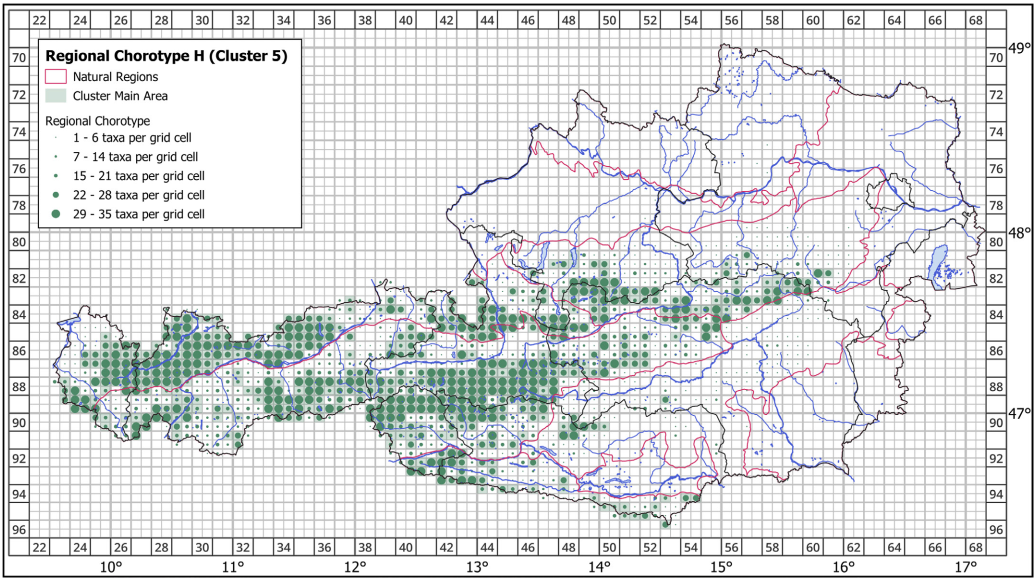


Altitude	Cluster key figures		Ranking by binding degree (b. d.)	
subnival	Number of species	34	*Poa alpina*	88
alpine	Maximum b. d. of species	88	*Galium anisophyllon*	87
subalpine	Minimum b. d. of species	59	*Selaginella selaginoides*	85
montane	Average b. d. of species	74	*Campanula scheuchzeri*	82
submont.	Standard deviation b. d. of species	7.3	*Persicaria vivipara*	82
colline	Number of grid cells	1874	*Geranium sylvaticum*	81
planar	Number of grid cells in main area	1029	*Carex sempervirens* s. str.	80
	Number of species in main area	34	*Viola biflora*	80
	Percentage of species b. d. >= 50	100%	*Crepis aurea*	80
	Overall assessment	87	*Saxifraga aizoides*	79

Regions	Habitat / Comments
Mainly distributed in subalpine and alpine regions of the Central Alps, the Northern and the Southern Alps.	Species occurring on various substrates and having different moisture requirements. Also including pH-indifferent species.

Plate 7: Regional Chorotype G: Map and characteristics. — **Tafel 7:** Regionaler Arealtyp G: Kartendarstellung und Kenndaten.

Regional Chorotype H (Cluster 5): Alps – from subalpine to alpine (subnival)

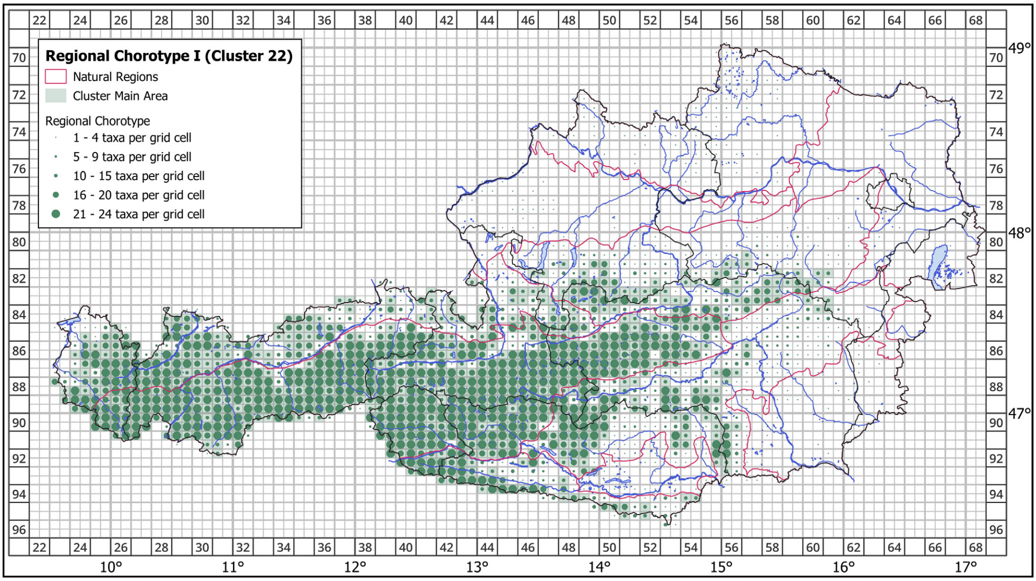


Altitude	Cluster key figures		Ranking by binding degree (b. d.)	
subnival	Number of species	45	*Festuca pumila*	74
alpine	Maximum b. d. of species	74	*Salix retusa* s. str.	70
subalpine	Minimum b. d. of species	31	*Myosotis alpestris*	69
montane	Average b. d. of species	56	*Silene acaulis*	69
submont.	Standard deviation b. d. of species	9.2	*Hornungia alpina*	67
colline	Number of grid cells	1360	*Minuartia gerardii*	66
planar	Number of grid cells in main area	560	*Veronica aphylla*	65
	Number of species in main area	35	*Carex atrata* s. str.	64
	Percentage of species b. d. >= 50	78%	*Helianthemum alpestre* s. str.	64
	Overall assessment	69	*Saxifraga androsacea*	63

Regions	Habitat / Comments
Main distribution in the following mountain groups: Rätikon, Lechtal Alps to Karwendel, Samnaun, eastern Stubai Alps, Hohe Tauern, Radstädter Tauern, Berchtesgaden Alps, Tennengebirge to Totes Gebirge, Ennstal Alps to Rax-Schneeberg and Southern Calcareous Alps.	Primary grasslands over calcareous bedrock, scree vegetation, nutrient-poor grassland, snowbed communities.

Plate 8: Regional Chorotype H: Map and characteristics. — **Tafel 8:** Regionaler Arealtyp H: Kartendarstellung und Kenndaten.

Regional Chorotype I (Cluster 22): Central Alps – from (montane) subalpine to alpine

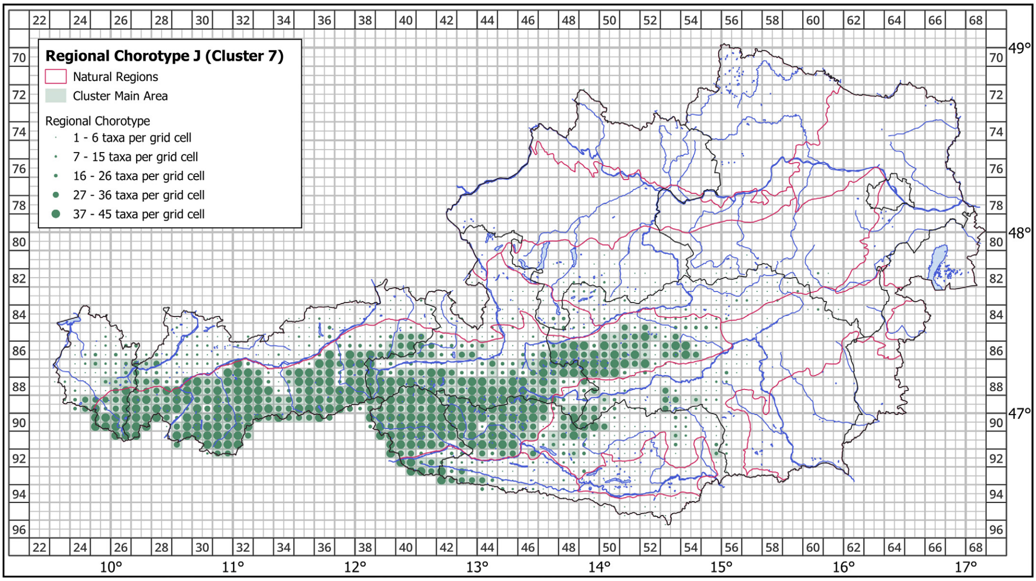


Altitude	Cluster key figures		Ranking by binding degree (b. d.)	
subnival	Number of species	24	*Anthoxanthum alpinum*	79
alpine	Maximum b. d. of species	79	*Agrostis rupestris*	78
subalpine	Minimum b. d. of species	58	*Saxifraga stellaris*	78
montane	Average b. d. of species	70	*Geum montanum*	77
submont.	Standard deviation b. d. of species	6.1	*Phleum rhaeticum*	77
colline	Number of grid cells	1627	*Peucedanum ostruthium*	77
planar	Number of grid cells in main area	884	*Pulsatilla alpina* s.lat.	75
	Number of species in main area	24	*Rhododendron ferrugineum*	74
	Percentage of species b. d. >= 50	100%	*Rumex alpestris*	74
	Overall assessment	83	*Veronica alpina*	74

Regions	Habitat / Comments
Distributed mainly in the following regions: Central Alps, Carnic Alps, and high parts of the North Alps.	Acidic grasslands or tall forb communities, mountain pastures.

Plate 9: Regional Chorotype I: Map and characteristics. — **Tafel 9:** Regionaler Arealtyp I: Kartendarstellung und Kenndaten.

Regional Chorotype J (Cluster 7): Central Alps – alpine (to subnival)

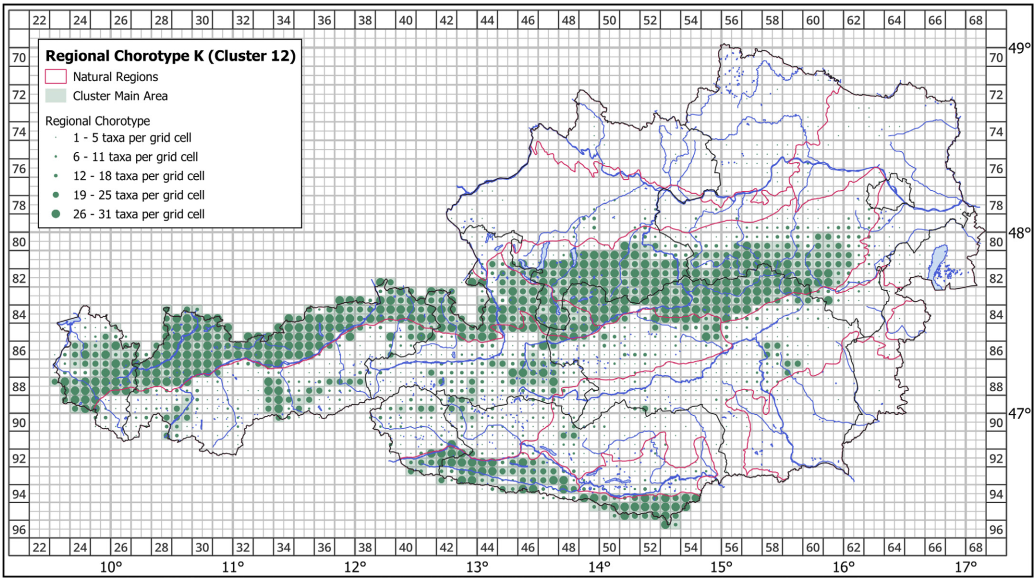


Altitude	Cluster key figures		Ranking by binding degree (b. d.)	
subnival	Number of species	68	*Saxifraga bryoides*	86
alpine	Maximum b. d. of species	86	*Leucanthemopsis alpina*	84
subalpine	Minimum b. d. of species	17	*Carex curvula*	83
montane	Average b. d. of species	57	*Luzula alpinopilosa* s. str.	82
submont.	Standard deviation b. d. of species	16.0	*Oreochloa disticha*	81
colline	Number of grid cells	1588	*Cardamine resedifolia*	79
planar	Number of grid cells in main area	451	*Phyteuma hemisphaericum* s. str.	77
	Number of species in main area	45	*Juncus trifidus* s. str.	77
	Percentage of species b. d. >= 50	66%	*Sedum alpestre*	77
	Overall assessment	70	*Carex frigida*	76

Regions	Habitat / Comments
Distributed mainly in the high-mountain parts of the Central Alps including Nockberge, in the western parts of the Carnic Alps, in the Seetaler Alps and to a lesser extent also on Saualpe, Koralpe and Stubalpe.	Calcifuge species, various habitats like: moist pastures, snowbed communities, moist scree vegetation, wind-exposed rocks, and acidic grassland.

Plate 10: Regional Chorotype J: Map and characteristics. — **Tafel 10:** Regionaler Arealtyp J: Kartendarstellung und Kenndaten.

Regional Chorotype K (Cluster 12): Northern and Southern Alps – from montane to alpine

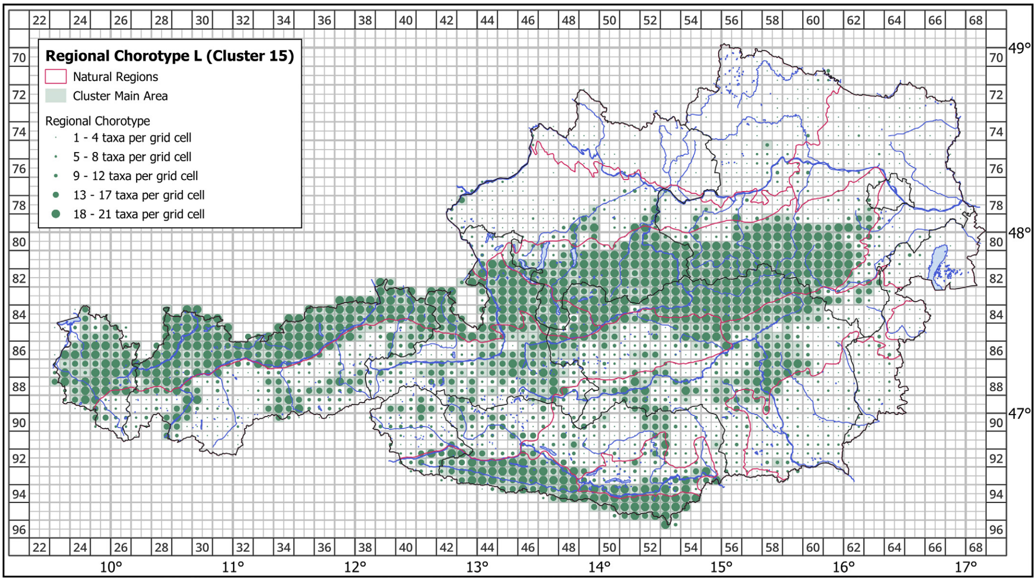


Altitude	Cluster key figures		Ranking by binding degree (b. d.)	
subnival	Number of species	38	*Valeriana saxatilis*	83
alpine	Maximum b. d. of species	83	*Globularia cordifolia* s. str.	78
subalpine	Minimum b. d. of species	36	*Kernera saxatilis*	78
montane	Average b. d. of species	60	*Carex firma*	77
submont.	Standard deviation b. d. of species	12.1	*Rhododendron hirsutum*	76
colline	Number of grid cells	1682	*Primula auricula*	73
planar	Number of grid cells in main area	648	*Gentiana clusii*	72
	Number of species in main area	31	*Carex mucronata*	72
	Percentage of species b. d. >= 50	82%	*Adenostyles alpina*	72
	Overall assessment	75	*Petasites paradoxus*	70

Regions	Habitat / Comments
Alpine regions of the Calcareous Alps, and the central-alpine Mesozoic sedimentary rocks in the following regions: Samnaun, eastern Stubai Alps, Glocknerdecke and other parts of the Tauern Window, Radstädter Tauern, scattered limestone occurrences in the eastern Central Alps incl. Grazer Bergland.	Specific to calcareous bedrock, various moisture requirements, e. g. limestone grassland, scree and rock communities, and sparse forests.

Plate 11: Regional Chorotype K: Map and characteristics. — **Tafel 11:** Regionaler Arealtyp K: Kartendarstellung und Kenndaten.

Regional Chorotype L (Cluster 15): Northern and Southern Alps – from (colline/submontane) montane to subalpine

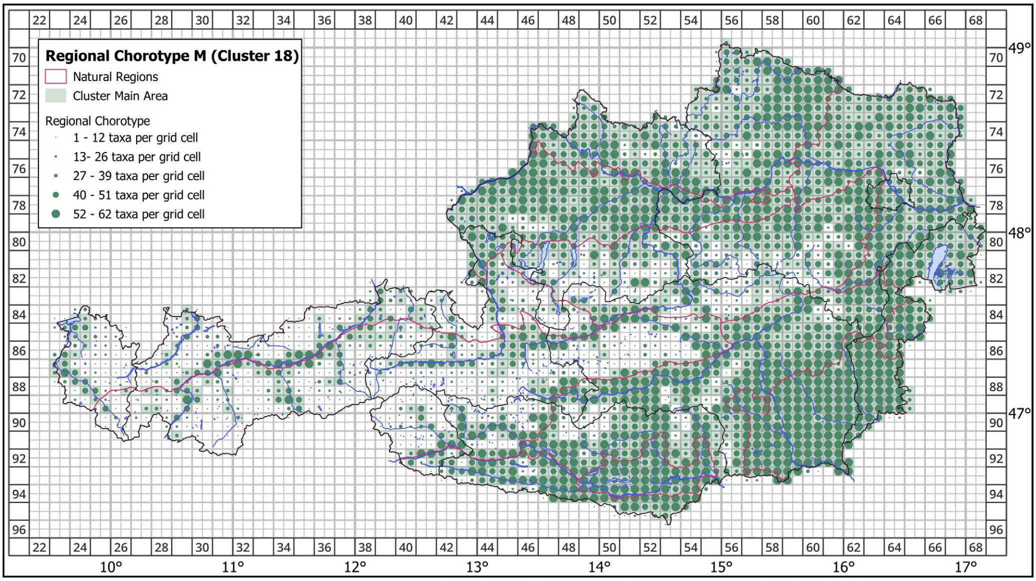


Altitude	Cluster key figures		Ranking by binding degree (b. d.)	
subnival	Number of species	35	*Sesleria caerulea* s. str.	72
alpine	Maximum b. d. of species	72	*Calamagrostis varia*	71
subalpine	Minimum b. d. of species	24	*Moehringia muscosa*	71
montane	Average b. d. of species	52	*Valeriana tripteris*	70
submont.	Standard deviation b. d.	13.6	*Gymnocarpium robertianum*	69
colline	Number of grid cells	2435	*Polygala chamaebuxus*	69
planar	Number of grid cells in main area	969	*Asplenium viride*	67
	Number of species in main area	21	*Epipactis atrorubens*	65
	Percentage of species b. d. >= 50	60%	*Buphthalmum salicifolium*	63
	Overall assessment	61	*Carex alba*	63

Regions	Habitat / Comments
Alpine regions of the Northern and Southern Calcareous Alps and the central-alpine Mesozoic, as well as in the southeastern part of the Central Alps over limestone (like Grazer Bergland or Nockberge) and in the Northern Prealpine Foreland along rivers originating from the Alps.	Calcicoles of various habitats, various moisture requirements, e. g. scree vegetation, limestone grassland, calcareous fens, damp-shady rocky slopes, rock crevice plant communities, and sparse forests.

Plate 12: Regional Chorotype L: Map and characteristics. — **Tafel 12:** Regionaler Arealtyp L: Kartendarstellung und Kenndaten.

Regional Chorotype M (Cluster 18): Prealpine Forelands, Klagenfurt Basin, Pannonian region – from planar-colline to montane

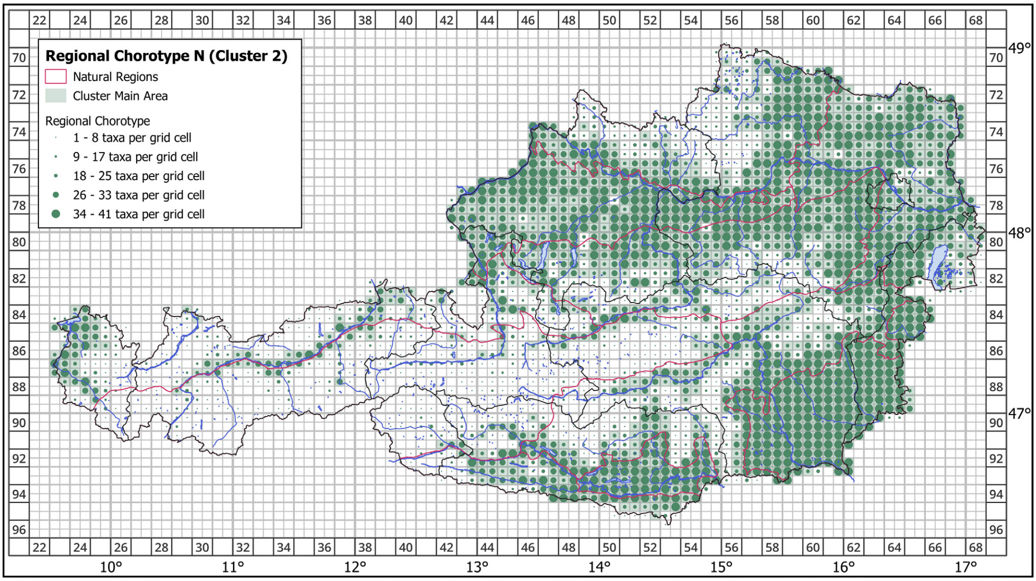


Altitude	Cluster key figures		Ranking by binding degree (b. d.)	
subnival	Number of species	63	*Chelidonium majus*	84
alpine	Maximum b. d. of species	84	*Fallopia convolvulus*	83
subalpine	Minimum b. d. of species	42	*Lapsana communis*	83
montane	Average b. d. of species	71	*Myosotis arvensis*	83
submont.	Standard deviation b. d. of species	8.8	*Convolvulus arvensis*	83
colline	Number of grid cells	2502	*Daucus carota*	82
planar	Number of grid cells in main area	1796	*Sonchus oleraceus*	81
	Number of species in main area	62	*Pastinaca sativa*	81
	Percentage of species b. d. >= 50	98%	*Viola arvensis*	81
	Overall assessment	84	*Calamagrostis epigejos*	81

Regions	Habitat / Comments
Widely distributed from planar to montane zone like in the Prealpine Forelands and Klagenfurt Basin. In the Central Alps only in the valleys, in the Northern Granite and Gneiss Highland mainly in the eastern part. Compared to chorotype B also distributed in the lowlands of the Pannonian Plains.	Many species are ruderal, e. g. nutrient-rich arable land, ruderal shrub fringes, gardens, and moist ruderal places.

Plate 13: Regional Chorotype M: Map and characteristics. — **Tafel 13:** Regionaler Arealtyp M: Kartendarstellung und Kenndaten.

Regional Chorotype N (Cluster 2): Prealpine Forelands, Klagenfurt Basin, Pannonian region and surroundings – from planar-colline to montane

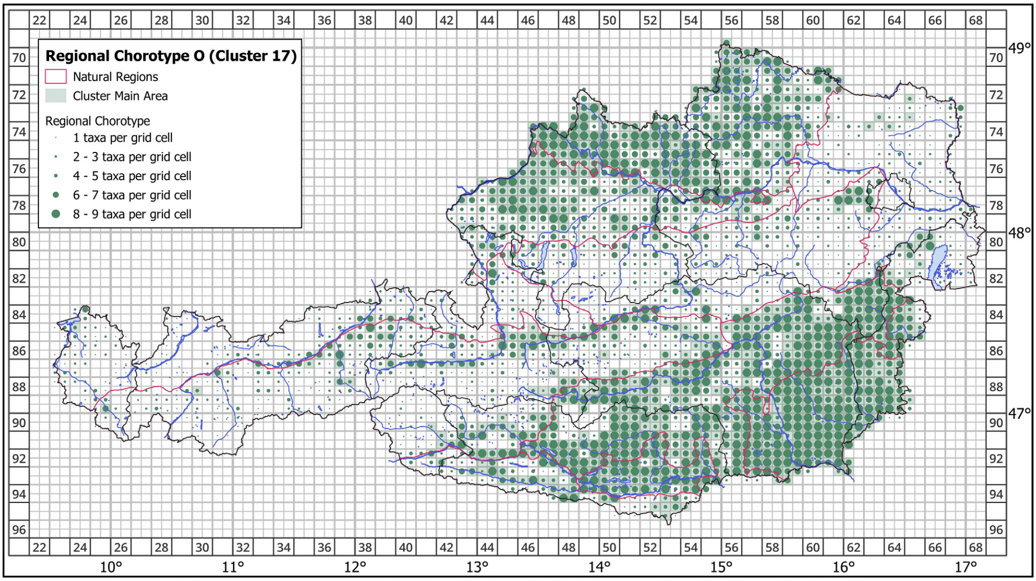


Altitude	Cluster key figures		Ranking by binding degree (b. d.)	
subnival	Number of species	41	*Euonymus europaeus*	84
alpine	Maximum b. d. of species	84	*Cornus sanguinea*	82
subalpine	Minimum b. d. of species	55	*Ligustrum vulgare*	78
montane	Average b. d. of species	68	*Quercus robur*	76
submont.	Standard deviation b. d. of species	6.8	*Prunus spinosa* s. str.	75
colline	Number of grid cells	2345	*Calystegia sepium* s. str.	75
planar	Number of grid cells in main area	1483	*Rubus caesius*	75
	Number of species in main area	41	*Clematis vitalba*	74
	Percentage of species b. d. >= 50	100%	*Viburnum opulus*	73
	Overall assessment	84	*Polygonatum multiflorum*	72

Regions	Habitat / Comments
Main distribution in the Prealpine Forelands, in the inner-alpine dry valleys, in the Klagenfurt Basin and in the Pannonian region. Compared to chorotype P fewer species are present in the Northern Granite and Gneiss Highland, occurring at lower elevations in the montane belt.	Various habitats, mostly with tree or scrub cover.

Plate 14: Regional Chorotype N: Map and characteristics. — **Tafel 14:** Regionaler Arealtyp N: Kartendarstellung und Kenndaten.

Regional Chorotype O (Cluster 17): Prealpine Forelands, Klagenfurt Basin, Northern Granite and Gneiss Highland – from colline to montane

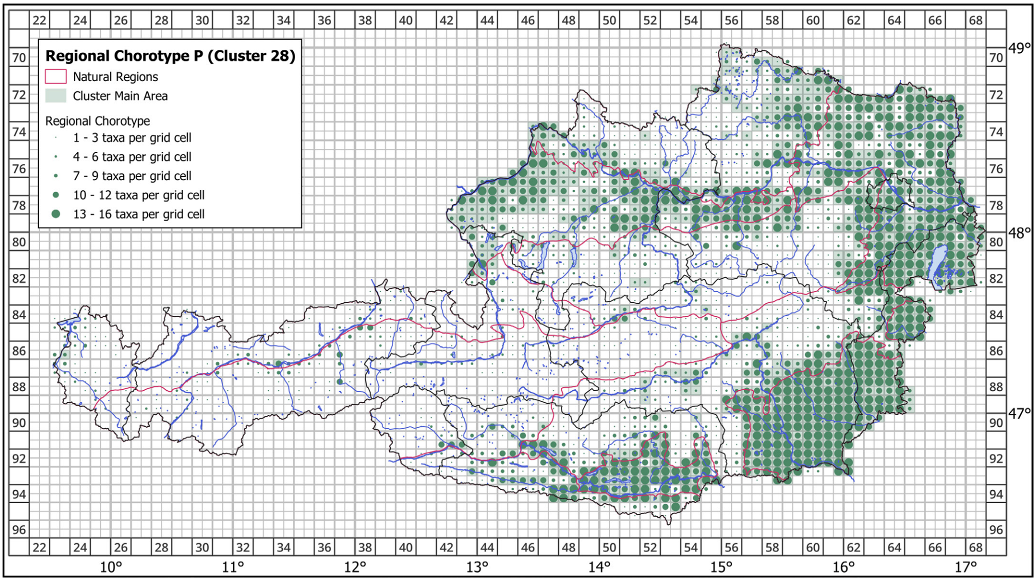


Altitude	Cluster key figures		Ranking by binding degree (b. d.)	
subnival	Number of species	21	*Carex brizoides*	58
alpine	Maximum b. d. of species	58	*Arabidopsis thaliana*	57
subalpine	Minimum b. d. of species	37	*Crepis capillaris*	57
▶ montane	Average b. d. of species	49	*Viscaria vulgaris*	55
▶ submont.	Standard deviation b. d. of species	5.8	*Hypochaeris radicata*	55
▶ colline	Number of grid cells	2390	*Persicaria hydropiper*	54
planar	Number of grid cells in main area	958	*Trifolium aureum*	52
	Number of species in main area	9	*Holcus mollis*	51
	Percentage of species b. d. >= 50	43%	*Trifolium dubium* s. str.	50
	Overall assessment	50		

Regions	Habitat / Comments
Distributed in the Prealpine Forelands, in the inner-alpine valleys, in the Klagenfurt Basin and the Northern Granite and Gneiss Highland. Less present in the Pannonian region.	Mostly calcifuge species of various habitats.

Plate 15: Regional Chorotype O: Map and characteristics. — **Tafel 15:** Regionaler Arealtyp O: Kartendarstellung und Kenndaten.

Regional Chorotype P (Cluster 28): Prealpine Forelands, Klagenfurt Basin, Pannonian Plains – from planar-colline to submontane

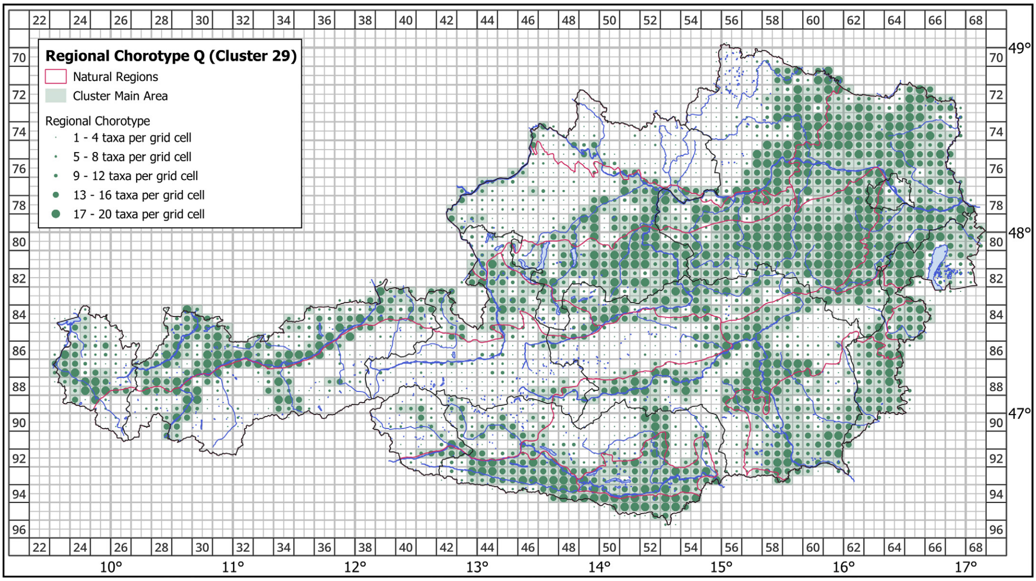


Altitude	Cluster key figures		Ranking by binding degree (b. d.)	
subnival	Number of species	32	*Lactuca serriola*	68
alpine	Maximum b. d. of species	68	*Setaria pumila*	67
subalpine	Minimum b. d. of species	24	*Echinochloa crus-galli*	65
montane	Average b. d. of species	50	*Bidens tripartita*	62
submont.	Standard deviation b. d. of species	9.7	*Setaria viridis*	60
colline	Number of grid cells	2223	*Solanum nigrum*	60
planar	Number of grid cells in main area	921	*Digitaria sanguinalis*	57
	Number of species in main area	16	*Typha latifolia*	55
	Percentage of species b. d. >= 50	50%	*Veronica polita*	54
	Overall assessment	56	*Persicaria mitis*	54

Regions	Habitat / Comments
Main distribution in the planar-colline zone, rising up to the montane belt. Mainly distributed in the Prealpine Forelands, some inner-alpine valleys, the Klagenfurt Basin and the Pannonian Plains.	Various, often anthropogenic habitats, e. g. arable land, vineyards, and ruderal places.

Plate 16: Regional Chorotype P: Map and characteristics. — **Tafel 16:** Regionaler Arealtyp P: Kartendarstellung und Kenndaten.

Regional Chorotype Q (Cluster 29): Calcareous Alps, parts of the Forelands, Pannonian region and surroundings – from planar-colline to montane

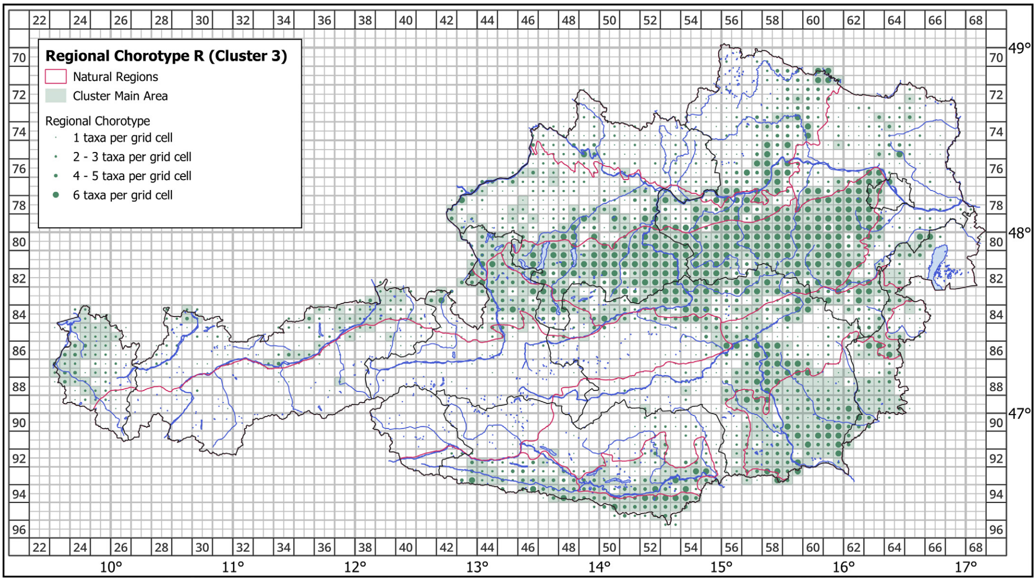


Altitude	Cluster key figures		Ranking by binding degree (b. d.)	
subnival	Number of species	20	*Viburnum lantana*	72
alpine	Maximum b. d. of species	72	*Centaurea scabiosa*	71
subalpine	Minimum b. d. of species	51	*Sanguisorba minor*	69
montane	Average b. d. of species	61	*Viola hirta*	68
submont.	Standard deviation b. d. of species	6.4	*Bromus erectus* s. str.	66
colline	Number of grid cells	2367	*Medicago falcata*	66
planar	Number of grid cells in main area	1391	*Convallaria majalis*	65
	Number of species in main area	20	*Salvia pratensis* s. str.	65
	Percentage of species b. d. >= 50	100%	*Vincetoxicum hirundinaria*	62
	Overall assessment	78	*Neottia nidus-avis*	61

Regions	Habitat / Comments
Main area in the eastern South Alps, in the Klagenfurt Basin, in the valleys of the lower-mountain part of the Central Alps, in the Grazer Bergland, in the Northern Alps, in the Pannonian region and surroundings, in the Northern Prealpine Foreland, particularly on the low terraces of the rivers Traun, Enns and Ybbs, as well as in the inner-alpine dry valleys.	Often more or less calcareous habitats, e. g. dry meadows, nutrient-poor grassland, sparse forests.

Plate 17: Regional Chorotype Q: Map and characteristics. — **Tafel 17:** Regionaler Arealtyp Q: Kartendarstellung und Kenndaten.

Regional Chorotype R (Cluster 3): Calcareous Alps, parts of the Forelands, and other regions – from colline to montane

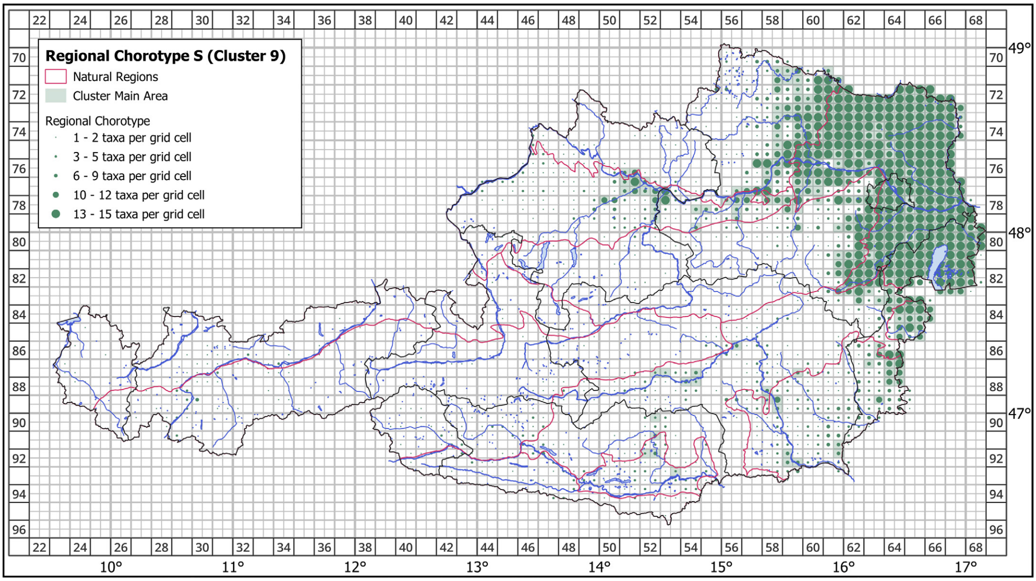


Altitude	Cluster key figures		Ranking by binding degree (b. d.)	
subnival	Number of species	30	*Euphorbia amygdaloides*	61
alpine	Maximum b. d. of species	61	*Cyclamen purpurascens*	55
subalpine	Minimum b. d. of species	29	*Atropa bella-donna*	55
montane	Average b. d. of species	44	*Galium odoratum*	54
submont.	Standard deviation b. d. of species	7.4	*Euphorbia dulcis*	52
colline	Number of grid cells	2442	*Hypericum hirsutum*	52
planar	Number of grid cells in main area	864		
	Number of species in main area	6		
	Percentage of species b. d. >= 50	20%		
	Overall assessment	42		

Regions	Habitat / Comments
Main distribution in the following regions: Northern Calcareous Alps, lower regions of Vorarlberg, Grazer Bergland, Southeastern Prealpine Foreland (Steirisches Hügelland), Günser Gebirge. In the Northern Granite and Gneiss Highland only on the border to the Pannonian region and in the Pannonian region only in the highest regions like Leithagebirge, and Leiser Berge.	Various habitats, species with higher binding degree occur over limestone in deciduous forests with e. g. *Tilia* sp. and *Acer* sp. ("Edellaubwälder"), or with *Fagus sylvatica*.

Plate 18: Regional Chorotype R: Map and characteristics. — **Tafel 18:** Regionaler Arealtyp R: Kartendarstellung und Kenndaten.

Regional Chorotype S (Cluster 9): Sub-Pannonic: Pannonian region and surroundings, Danube Valley



Altitude	Cluster key figures		Ranking by binding degree (b. d.)	
subnival	Number of species	32	*Eryngium campestre*	82
alpine	Maximum b. d. of species	82	*Falcaria vulgaris*	79
subalpine	Minimum b. d. of species	21	*Mercurialis annua*	70
montane	Average b. d. of species	51	*Consolida regalis*	70
submont.	Standard deviation b. d. of species	13.6	*Berteroa incana*	66
colline	Number of grid cells	1800	*Centaurea stoebe* s.lat.	64
planar	Number of grid cells in main area	438	*Lepidium draba*	61
	Number of species in main area	15	*Scabiosa ochroleuca*	60
	Percentage of species b. d. >= 50	47%	*Lathyrus tuberosus*	58
	Overall assessment	60	*Descurainia sophia*	57

Regions	Habitat / Comments
Main distribution in the following regions: Pannonian region, eastern part of the Northern Granite and Gneiss Highland on the border to the Pannonian region, Central Burgenland, around Günser Gebirge, Danube valley up to Linz and along tributary rivers.	Thermophilic species adapted to the Pannonian climate. Various habitats, e.g. xerothermic grassland, (semi) dry meadows, waysides, arable land, and ruderal places.

Plate 19: Regional Chorotype S: Map and characteristics. — **Tafel 19:** Regionaler Arealtyp S: Kartendarstellung und Kenndaten.

In this study, different hierarchical clustering methods and distance measures showed quite similar chorotypes and proved better suitability of the Ward method in combination with the Euclidean distance measurement based on the binding degree. Nonetheless, applying other pattern recognition methods like network clustering may offer additional insights into the detection of chorotypes.

The distribution of vascular plant species is generally influenced by internal and external factors, like ecological-abiotic, biotic and historical factors (Müller & al. 2021). Conducting a further study on the ecological parameters, such as ecological indicator values adapted to Austria (Karrer 2024) of the regional chorotypes through quantitative analysis, would enhance the characterisation of the recognized chorotypes. This could provide additional insights into the analysis of the factors influencing regional chorotypes of the Austrian vascular plant flora, such as macroclimate, altitude, and edaphic factors.

As the natural landscape classification of Austria by Sauberer & Grabherr (1995a) is based on geology, climate, cultural landscape and biogeographical aspects, the chorotypes are related to the natural regions. For example, the chorotypes E to L reflect the association of the assigned species to the alpine regions. Species of the chorotypes M to R are at least partly distributed in the Prealpine Forelands. Chorotype S reflects the association of thermophilous species to the Continental-Pannonian climate and is mainly restricted to the Pannonian region.

Chorotypes A, B, C and M include common species in Austria distributed in nearly all natural regions, but their distribution differs in altitude. Species of chorotype A are distributed widely, whereas chorotype B ranges from the colline to the montane zone. Chorotype M ranges from the planar to the montane zone, and species of chorotype C occur from the colline to the subalpine zone, with the exception of the Pannonian region.

Chorotypes D, K and L include many calcicoles and reflect the association of the assigned species to calcareous bedrock, but differ in altitude. Species of chorotype D are distributed mainly from the colline to montane zone in all natural regions of Austria, whereas species of chorotype L are mainly found from the montane to the subalpine zone in the Alps and species of chorotype K are growing from the montane to alpine zone. In contrast, chorotypes J and O include many calcifuge species. Chorotype J reflects the distribution of calcifuge species in the alpine zone to acidic bedrock, whereas the main distribution of chorotype O ranges from the colline to the montane zone.

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Electronic Supplement

The following data is provided within the electronic supplement:

Fig. S1: Number of species with binding degree of at least 50 at different cutlevels (Ward method and Euclidean distance).

Fig. S2: Cluster dendrogram (aggregation of similar species), branches at cutlevel 30 marked by colour and cluster number (Ward method and Euclidean distance).

The electronic supplement is accessible under following links:
https://doi.org/10.5281/zenodo.13934418
https://www.zobodat.at/pdf/neil_supp/NEIL_15_FigS1-FigS2.zip

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