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Biogeographical classification of Austria based on hierarchical cluster analysis of vascular plant distributions

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Abstract: Applying hierarchical cluster analysis on data from the project "Floristic Mapping of Austria", a biogeographical classification of Austria is established. Various clustering methods and similarity indices are tested for their suitability, and their performance is assessed via stability tests. The best results are achieved by the Ward method in combination with Euclidean distance. For validation, the obtained results are compared with existing natural landscape classification schemes. The results are congruent, and the level of concordance to the natural landscape classification is satisfying. It is shown that hierarchical cluster analysis based only on plant distribution data is suitable for a biogeographical classification of Austria.

Key words: hierarchical cluster analysis; biogeographical classification of Austria; cluster analysis; Floristic Mapping of Austria; phytogeography

Zusammenfassung: **Biogeographische Raumgliederung Österreichs mittels hierarchischer Clusteranalyse auf Grundlage der Gefäßpflanzenverbreitung**
Mittels hierarchischer Clusteranalyse basierend auf den Daten des Projekts „Floristische Kartierung Österreichs" wird eine biogeographische Raumgliederung Österreichs erstellt. Es werden unterschiedliche Clustermethoden und Ähnlichkeitsmaße auf ihre Eignung überprüft und es wird ihre Stabilität getestet. Die besten Resultate lieferten die Ward-Methode in Kombination mit dem Euklidischen Distanzmaß. Zur Validierung werden die Ergebnisse mit vorhandenen naturräumlichen Gliederungen verglichen. Der Grad der Übereinstimmung zur naturräumlichen Gliederung ist zufriedenstellend. Es wird dargestellt, dass eine hierarchische Clusteranalyse, die ausschließlich auf floristischen Verbreitungsdaten basiert, zur Erstellung einer biogeographischen Raumgliederung Österreichs geeignet ist.

Introduction

Floristic division of territories is a basic aim of phytogeography. Scales run from worldwide classifications (e. g. Diels 1908, Meusel & al. 1965, Takhtajan 1977, 1986) down to fine-resolution attempts for small areas (e. g. several European towns). At medium scales, earlier systems were based on expert knowledge and on selective comparisons. More recent approaches introduced statistical methods when the first computerised classifications of biogeographical spatial units based on comprehensive distribution data were performed in the 1990s. Due to the limited computational resources of that time, data set sizes had then to be reduced prior to analysis by decreasing the number of taxa or by narrowing the study area. Thomas Wohlgemuth carried out a biogeographical

DOI: https://doi.org/10.5281/zenodo.5818991 Original article analysis of Switzerland with the statistical program MULVA using the Jaccard index and the minimum-variance method (Wohlgemuth 1996). Heiko Korsch performed a biogeographical analysis of East Germany, but due to the big data volume, a hierarchical cluster analysis was not possible at that time, hence k-means clustering was done with the statistical program SPSS (Korsch 1999). Van Landuyt & al. (2011) also applied a non-hierarchical k-means cluster analysis to vascular plant distribution data of the northern part of Belgium, identifying 18 species clusters and 9 phytogeographic spatial units, whereas the Belgian pioneer study on numerical analysis of vascular plant distribution data by Boon (1978) had to be restricted to a selection of putative indicator species. In 2012, a hierarchical cluster analysis of the flora of the Iberian Peninsula and the Balearic archipelago was performed with the program PAST (Hammer & al. 2001) using the Jaccard index and UPGMA[1] on grid cells of 50 km × 50 km (Moreno Saiz & al. 2013). The approach by Poldini (1991; see also Poldini & Vidali 1985, 1986) for north-eastern Italy (Friuli-Venezia Giulia) differs from the others by jointly using data on species distributions, various biological attributes of the species, as well as external environmental factors.

A natural landscape classification of Austria was established by Sauberer & Grabherr (1995a) based on expert knowledge by taking into account different physiographical aspects like geology, climate, and biogeographical aspects (e. g. glacial refugia). As plant distributions are affected by the same factors, it should be possible to delimit natural regions based on plant distribution data by using quantitative methods. A first biogeographical classification based on floristic observation records was carried out for Austria on data as of December 2017 (Billensteiner, 2020) and is repeated in the current study with an updated and enhanced data set (data as of January 2021). Here it will be shown that hierarchical cluster analysis, comparing various cluster methods and similarity indices to assess their suitability, based only on floristic data is suitable for the determination of biogeographical regions.

Data and Methods

Data

The project "Floristic Mapping of Austria" gathers distribution data of vascular plants in Austria. This project was initiated in the 1960s (Ehrendorfer & Hamann 1965, Niklfeld 1971) within the international framework of "Mapping the Flora of Central Europe" (Niklfeld 1997). The aim is to provide a comprehensive nationwide survey of the distribution of all vascular plant species in Austria (Niklfeld & al. 2008). Until now, the database contains approximately 2.42 million records for Austria, 98% thereof

1 Unweighted Pair Group Method with Arithmetic mean

originating from field records (data as of January 2021). As a taxonomic reference, the checklist "Liste der Gefäßpflanzen Mitteleuropas" (Ehrendorfer 1967; Gutermann & Niklfeld 1973) including later revisions (Gilli & al. 2019) was used.

Methods

In general, hierarchical cluster analysis is used to detect structural similarity in a data set, as similar objects are grouped into clusters. In this case, grid cells were grouped into biogeographical regions based on their floristic similarity. The analysis was performed with the statistical software R (R Core Team 2021) by using the package fastcluster (Müllner 2013) on floristic observation records. The floristic similarity of grid cells (3′ longitude, 5′ latitude, average area of 35 km²) was calculated based on the presence data of vascular plant species. As hierarchical agglomerative clustering algorithm, the Complete Linkage method (Furthest-Neighbour method) was applied by using the Jaccard index, the Dice index (Sørenson index) and the Euclidean distance measure as similarity indices, as they are suitable for dichotomous variables like presence/absence data (Johnston 1976, Bacher & al. 2010). The Ward method (minimum-variance method) was applied by using the Euclidean distance measure. The R package fastcluster calculates the Euclidean distance as the dissimilarity index for the Ward method (Müllner 2013).

Stability tests were conducted on two differently sized data sets (complete data and one without grid cells at the national border) in order to prove that a small change of the input data has only a small effect on the result (Bacher & al. 2010). For identifying the optimal number of clusters, the variance between cutlevels was determined by utilizing the Krzanowski and Lai index (Krzanowski & Lai 1988) of the NbClust package in R (Charrad & al. 2014). The results of the cluster analysis were visualised as cluster dendrograms and as maps outlining the biogeographical regions.

The resulting clusters were compared visually with the natural landscape classification of Austria by Sauberer & Grabherr (1995a), which is based on geological, climatic and biogeographical aspects and the cultural landscape. This classification has been used for the delimitation of the "Natura 2000 areas" as implementation of the Habitats Directive (Council Directive 92/43/EEC) in Austria (Sauberer & Grabherr 1995b).

Figure 1 outlines the geology of Austria based on Geologische Bundesanstalt (2013), the climate (Bobek 1975), and the natural landscape classification according to Sauberer & Grabherr (1995a). The Northern Alps (predominantly limestone), also called Northern Calcareous Alps, are divided into a middle and western part (1) and an eastern part (2). The Central Alps (predominantly siliceous rocks) are subdivided into a high-mountain part (3) and a lower-mountain part (5). In the south, the Southern Alps (predominantly limestone), also called Southern Calcareous Alps (4), are neighbouring the Klagenfurt Basin (6). As non-alpine regions, the Southeastern Prealpine Foreland (7), the Northern Prealpine Foreland (9), the Pannonian region (8), and the Northern

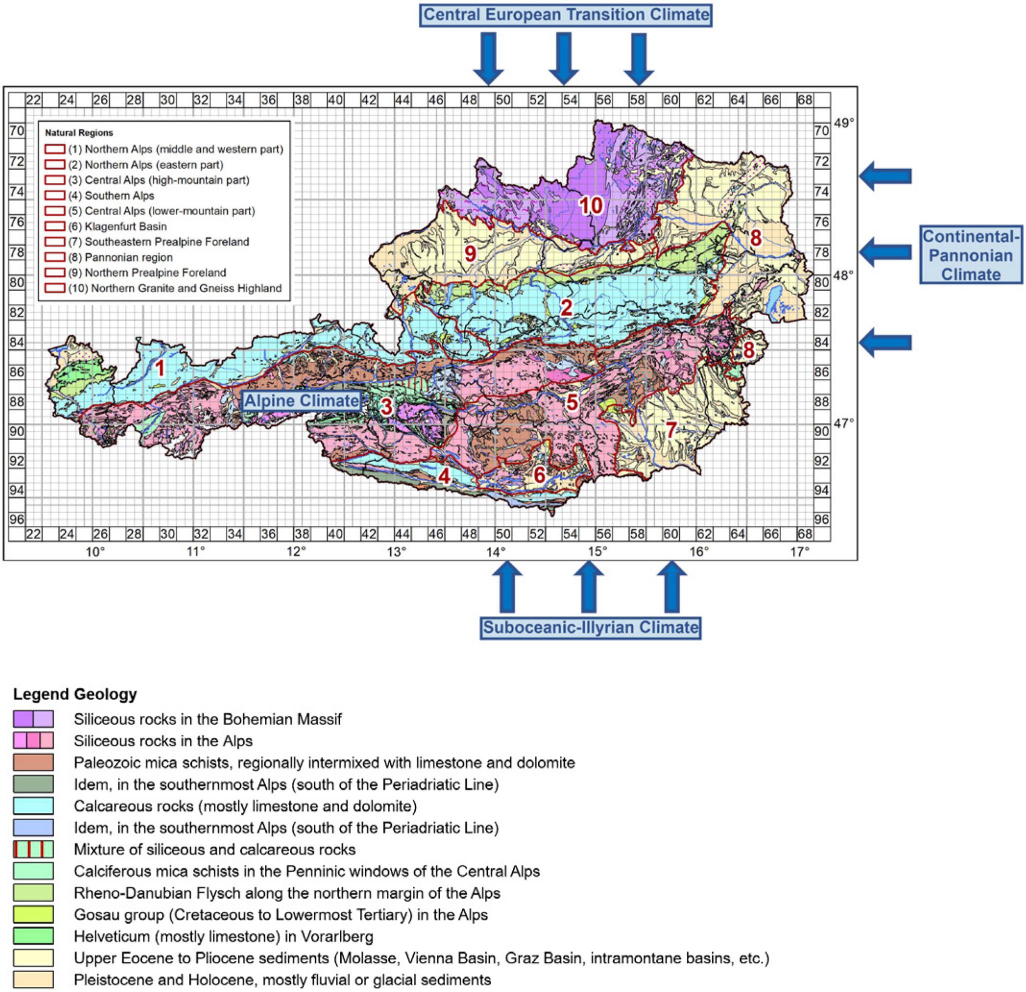

Fig. 1: Natural regions (SAUBERER & GRABHERR 1995a), geology (based on GEOLOGISCHE BUNDESANSTALT 2013), and climate of Austria (BOBEK 1975). — **Abb. 1:** Naturräume (SAUBERER & GRABHERR 1995a), Geologie basierend auf GEOLOGISCHE BUNDESANSTALT (2013) und Klima Österreichs (BOBEK 1975).

Granite and Gneiss Highland (10) are distinguished. The territory of Austria is subject to various climate regimes. The inner-alpine regions are characterised by the alpine climate. The eastern part of the Southern Alps, the Klagenfurt Basin and the Southeastern Prealpine Foreland are influenced by the suboceanic-Illyrian climate. The Pannonian region is characterised by the continental-Pannonian climate, and the Central European transitional climate affects the Northern Granite and Gneiss Highland and the Northern Prealpine Foreland (BOBEK 1975).

Results and Discussion

Among the considered methods and similarity indices, the Ward method in combination with Euclidean distance yielded, in comparison to other algorithms and similarity indices, the fewest chaining phenomena (chaining is the sequential joining of individual entities), and did not result in any outliers (Fig. 2). In contrast, using the Complete Linkage method resulted in chaining effects, and in outliers or very small clusters for all applied similarity indices (see electronic supplement Figs. S1–S4). The Complete Linkage method with Euclidean distance, the Jaccard index and the Dice index led to classifications with reduced accordance to the natural regions (see electronic supplement, Figs. S5–S8).

The Ward method with Euclidean distance resulted in the best concordance of delimited regions with previously identified regions (Sauberer & Grabherr 1995a).

The stability tests on differently sized data sets (Ward method and Euclidean distance) resulted in a different order of aggregation, but the geographic distribution of regions (e. g. the Northern Granite and Gneiss Highland, the Pannonian region, the Southeastern and the Northern Prealpine Foreland and the Southern Alps) was similar. Additionally, the results (Ward method and Euclidean distance) were compared with those from the master thesis (Billensteiner 2020), which was based on the data as of December 2017 with fewer floristic observation records. In the current study, the

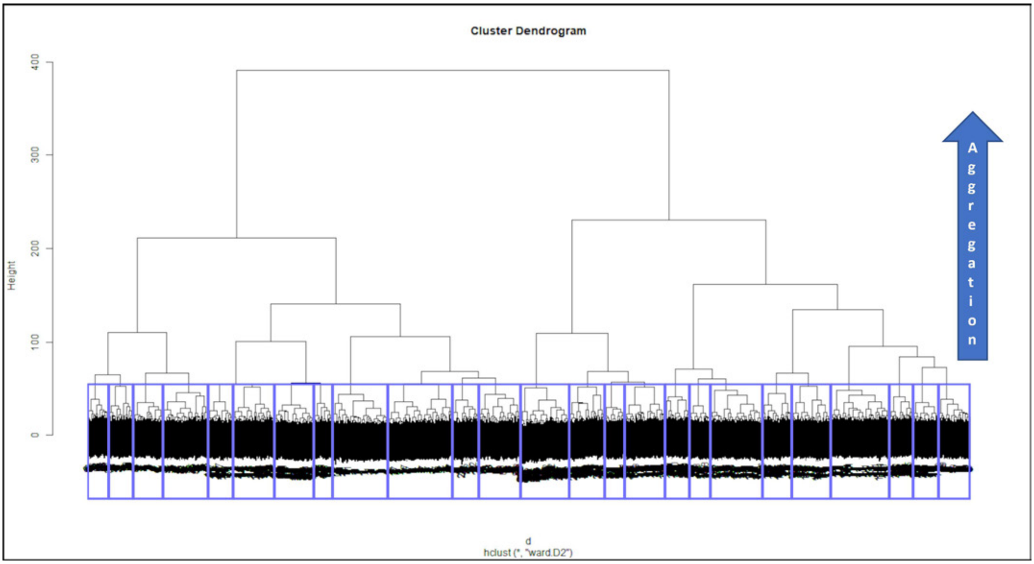

Fig. 2: Cluster dendrogram based on Ward method and Euclidean distance; blue rectangles indicate clusters at cutlevel 25. — **Abb. 2:** Cluster-Dendrogram basierend auf der Ward-Methode und dem Euklidischen Distanzmaß; blaue Rechtecke markieren die Äste auf Cutlevel 25.

clustering was different at some cutlevels. At cutlevel 30, the delimitation of the calcareous high-mountain part in the eastern part of the Northern Alps was narrower, and the Manhartsberg region was identified as a distinct region. Nevertheless, the overall accordance of the delimitation of the geographic units was high. Therefore, the stability of the clustering algorithm is deemed sufficient.

Using the index of Krzanowski & Lai (1988) on the result of the cluster analysis (Ward method and Euclidean distance), the optimal numbers of clusters in the range from 1 to 29 clusters were 3, 6, 12, 19, 21 and 25 (see electronic supplement, Fig. S9).

Figure 3 to Fig. 22 show the classifications between cutlevel 2 and cutlevel 30 based on the Ward method in combination with Euclidean distance. The blue arrows indicate the described differences between the preceding and the current cutlevel. At cutlevel 2 (Fig. 3), the highest aggregation level, the higher Alps were segregated from the other regions, and at cutlevel 3 (Fig. 4), the high-mountain part of the Central Alps was also separated from the remaining parts of the higher regions of the Alps. At cutlevel 4 (Fig. 5), the Pannonian region was differentiated, and at cutlevel 5 (Fig. 6), the lower-mountain part and the valleys of the Central Alps were separated. The Northern Prealpine Foreland and the Northern Granite and Gneiss Highland were differentiated at cutlevel 6 from the Southeastern Prealpine Foreland, the Klagenfurt Basin and the low regions of the Central Alps (Fig. 7). At cutlevel 7, a division of the Northern Alps into alpine areas and into montane regions and valleys occurred (Fig. 8). At cutlevel 8, the Pannonian plains and lower hillsides were distinguished from higher regions like the Manhartsberg area, the foothills of the Alps along the so-called Thermenlinie, and the Leithagebirge (Fig. 9). At cutlevel 9, the high-mountain part of the Central Alps was divided further into predominantly high alpine areas and regions with both, high-alpine and montane parts (Fig. 10). The Northern Granite and Gneiss Highland and the Hausruck were separated at cutlevel 10 from the Northern Prealpine Foreland (Fig. 11). At cutlevel 11, the Southeastern Prealpine Foreland was differentiated from the Klagenfurt Basin and the lower regions of the Central Alps (Fig. 12). A separation of the middle and eastern Northern Alps into regions with alpine and montane parts on one side and the almost exclusively montane northeastern Pre-Alps on the other side appeared at cutlevel 12 (Fig. 13). The Southern Alps were differentiated from the regions of the Northern Alps at cutlevel 13 (Fig. 14). By comparing the clustering at cutlevels 13 and 30, further division of the following regions took place: Alps, Southeastern Prealpine Foreland, Northern Prealpine Foreland, Thermenalpen SW of Vienna, Klagenfurt Basin, and the Pannonian region. The Klagenfurt Basin is differentiated from the other regions at cutlevel 29.

The comparison with the natural landscape classification of Austria by Sauberer & Grabherr (1995a) was done on the classification at cutlevel 12, as this was the closest optimal number of clusters (10 natural regions). In general, the accordance was good, nevertheless some differences were found (see Fig. 23). In the present classification, only the eastern part of the Middle Burgenland hillside was assigned to the Pannonian region, the main part was added to the Southeastern Prealpine Foreland (also still at cutlevel 30). The Pannonian region was differentiated further into lowlands and

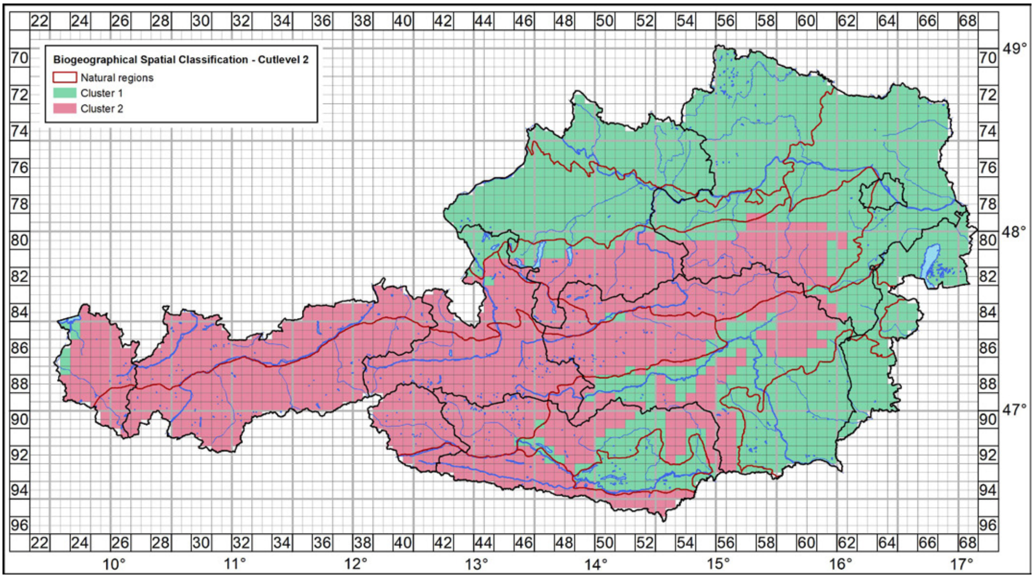

Fig. 3: Geographic delimitation of clusters identified at cutlevel 2 – separation of the higher parts of the Alps (Northern Alps, higher Central Alps, Southern Alps) from the other regions. — **Abb. 3:** Geographische Abgrenzung der identifizierten Cluster auf Cutlevel 2 – Trennung des höheren Alpengebiets (Nordalpen, höhere Zentralalpen, Südalpen) von den übrigen Regionen.

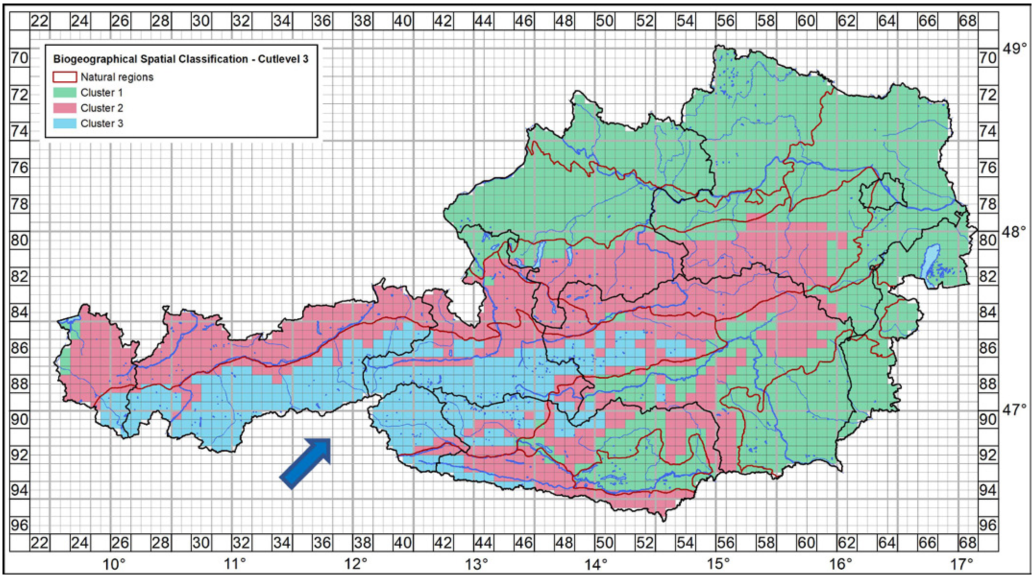

Fig. 4: Geographic delimitation of clusters identified at cutlevel 3 – differentiation of the Central Alps (high-mountain part) from the other parts of the Alps of higher altitude. The blue arrow indicates the area in which cutlevels 3 and 2 (Fig. 3) differ. — **Abb. 4:** Geographische Abgrenzung der identifizierten Cluster auf Cutlevel 3 – Trennung des Hochgebirgsanteils der Zentralalpen von den übrigen Teilen des höheren Alpengebiets. Der blaue Pfeil markiert den Bereich, in dem sich Cutlevel 3 und Cutlevel 2 (Abb. 3) unterscheiden.

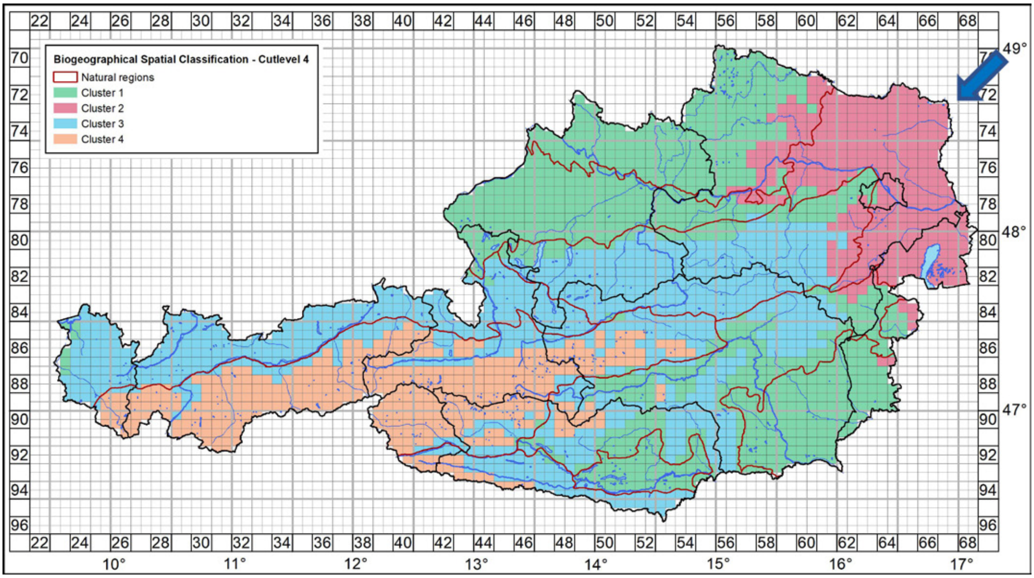

Fig. 5: Geographic delimitation of clusters identified at cutlevel 4 – differentiation of the Pannonian region. The blue arrow indicates the area in which cutlevels 4 and 3 (Fig. 4) differ. — **Abb. 5:** Geographische Abgrenzung der identifizierten Cluster auf Cutlevel 4 – Abtrennung der Pannonischen Region. Der blaue Pfeil markiert den Bereich, in dem sich Cutlevel 4 und Cutlevel 3 (Abb. 4) unterscheiden.

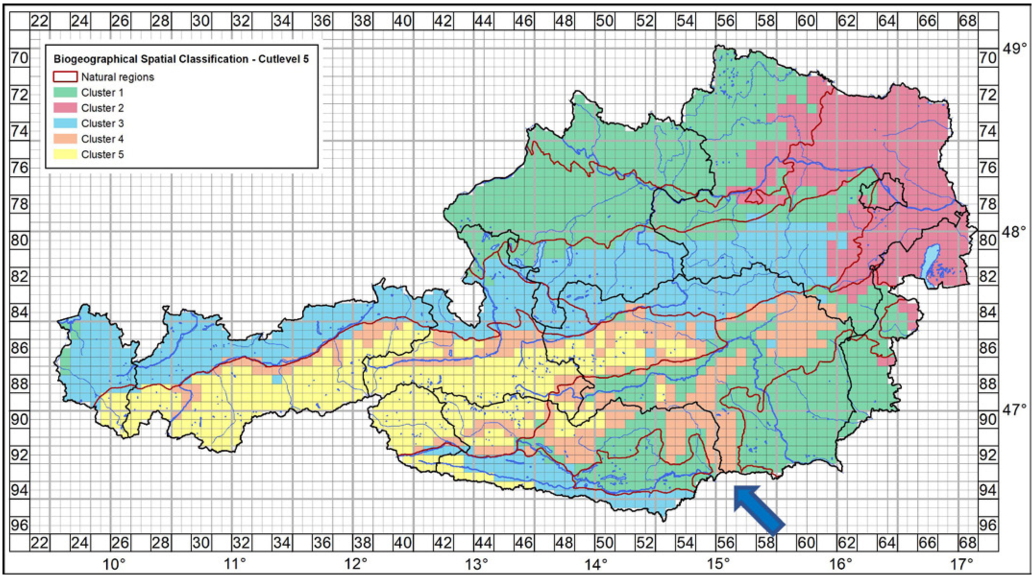

Fig. 6: Geographic delimitation of clusters identified at cutlevel 5 – separation of the Central Alps (lower-mountain part) from the Northern and Southern Alps. The blue arrow indicates the area in which cutlevels 5 and 4 (Fig. 5) differ. — **Abb. 6:** Geographische Abgrenzung der identifizierten Cluster auf Cutlevel 5 – Trennung der niedrigeren Gebirgsanteile der Zentralalpen von den Nord- und Südalpen. Der blaue Pfeil markiert den Bereich, in dem sich Cutlevel 5 und Cutlevel 4 (Abb. 5) unterscheiden.

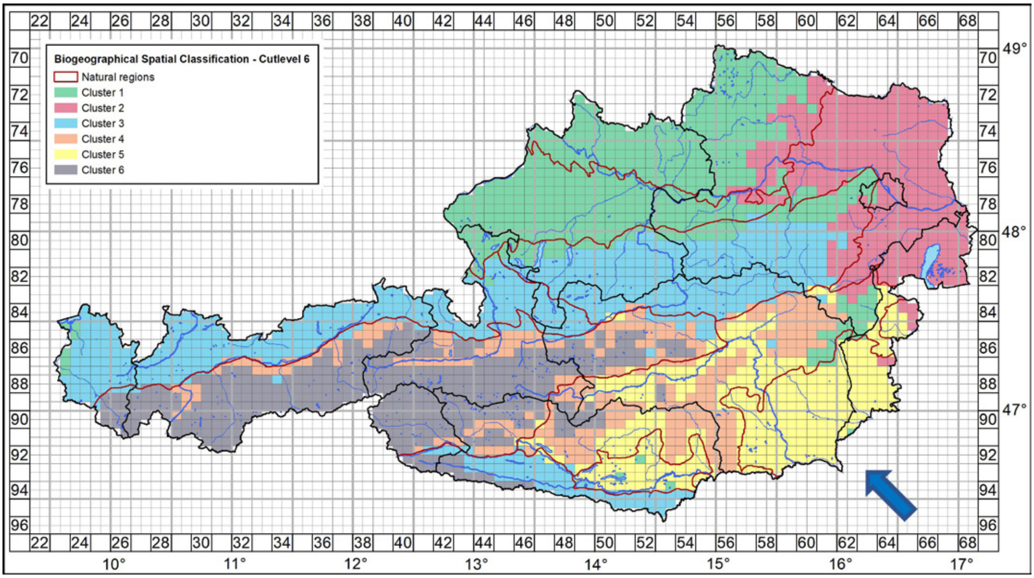

Fig. 7: Geographic delimitation of clusters identified at cutlevel 6 – differentiation of the Northern Foreland and the Northern Granite and Gneiss Highland from the Southeastern Foreland, the Klagenfurt Basin and the lower regions of the Central Alps. The blue arrow indicates the area in which cutlevels 6 and 5 (Fig. 6) differ. — **Abb. 7:** Geographische Abgrenzung der identifizierten Cluster auf Cutlevel 6 – Trennung zwischen Nördlichem Vorland und Nördlichem Granit- und Gneishochland einerseits, und Südöstlichem Vorland, Klagenfurter Becken und tief gelegenen Anteilen der Zentralalpen, andererseits. Der blaue Pfeil markiert den Bereich, in dem sich Cutlevel 6 und Cutlevel 5 (Abb. 6) unterscheiden.

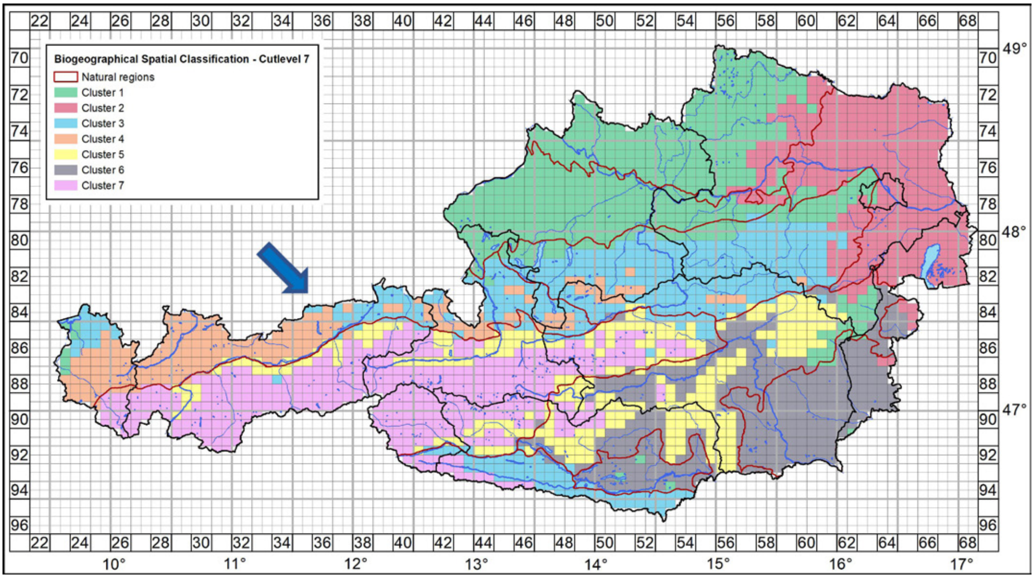

Fig. 8: Geographic delimitation of clusters identified at cutlevel 7 – further breakdown of the Northern Alps (alpine areas – montane regions and valleys). The blue arrow indicates the area in which cutlevels 7 and 6 (Fig. 7) differ. — **Abb. 8:** Geographische Abgrenzung der identifizierten Cluster auf Cutlevel 7 – weitere Unterteilung der Nordalpen (Hochgebirgsregionen – vorwiegend montane Regionen und Täler). Der blaue Pfeil markiert den Bereich, in dem sich Cutlevel 7 und Cutlevel 6 (Abb. 7) unterscheiden.

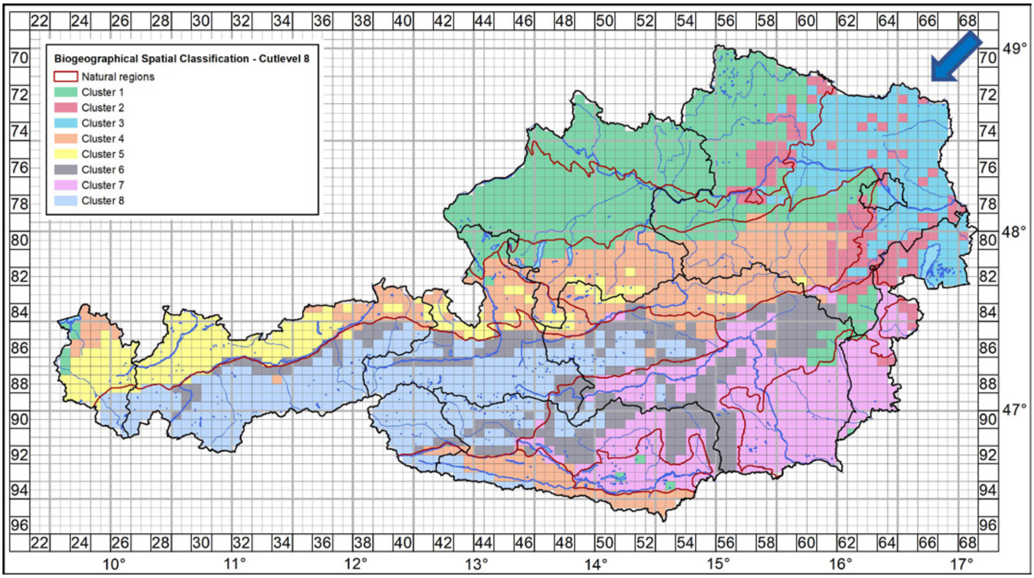

Fig. 9: Geographic delimitation of clusters identified at cutlevel 8 – distinction of the Pannonian plains and low hillsides against the Manhartsberg area, the marginal stripe of the Alps SW of Vienna (Thermenalpen), and some marked interior hillsides (e.g. Leithagebirge). The blue arrow indicates the area in which cutlevels 8 and 7 (Fig. 8) differ. — **Abb. 9:** Geographische Abgrenzung der identifizierten Cluster auf Cutlevel 8 – Trennung der Pannonischen Ebenen und niedrigen Hügelländer einerseits von Manhartsberggebiet, Thermenalpen und einigen ausgeprägteren inneren Hügelgebieten (z. B. Leithagebirge). Der blaue Pfeil markiert den Bereich, in dem sich Cutlevel 8 und Cutlevel 7 (Abb. 8) unterscheiden.

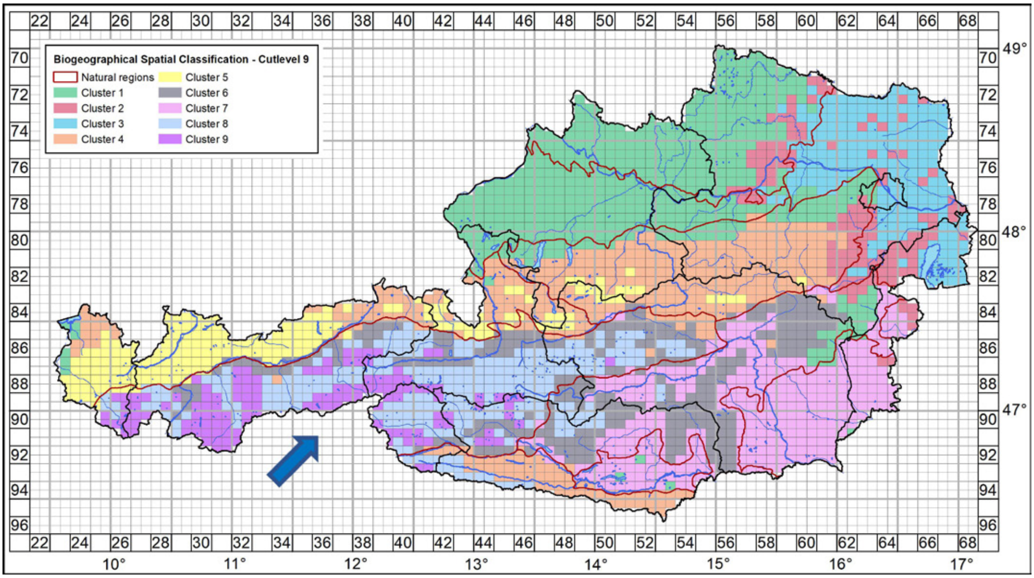

Fig. 10: Geographic delimitation of clusters identified at cutlevel 9 – further differentiation of the high-mountain part of the Central Alps (predominantly high alpine areas – regions with both, high-alpine and montane parts). The blue arrow indicates the area in which cutlevels 9 and 8 (Fig. 9) differ. — **Abb. 10:** Geographische Abgrenzung der identifizierten Cluster auf Cutlevel 9 – weitere Unterteilung des Hochgebirgsanteils der Zentralalpen (vorwiegend hochalpine Anteile – Regionen mit sowohl hochalpinen als auch montanen Anteilen). Der blaue Pfeil markiert den Bereich, in dem sich Cutlevel 9 und Cutlevel 8 (Abb. 9) unterscheiden.

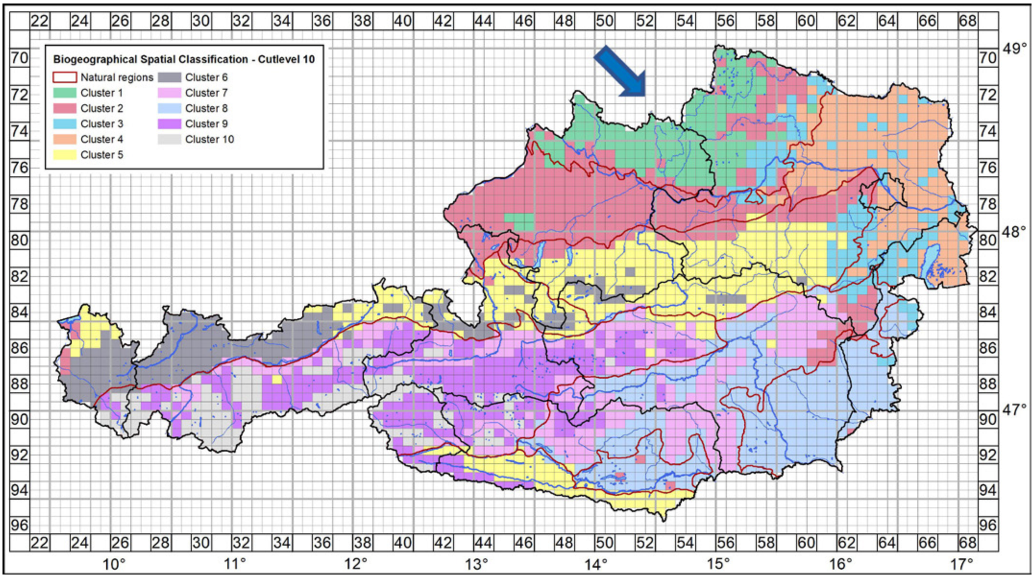

Fig. 11: Geographic delimitation of clusters identified at cutlevel 10 – separation of the Northern Foreland from most of the Northern Granite and Gneiss Highland and the Hausruck upland. The blue arrow indicates the area in which cutlevels 10 and 9 (Fig. 10) differ. — **Abb. 11:** Geographische Abgrenzung der identifizierten Cluster auf Cutlevel 10 – Trennung des Nördlichen Vorlands vom Großteil des Nördlichen Granit- und Gneishochlands und dem Hausruck-Bergland. Der blaue Pfeil markiert den Bereich, in dem sich Cutlevel 10 und Cutlevel 9 (Abb. 10) unterscheiden.

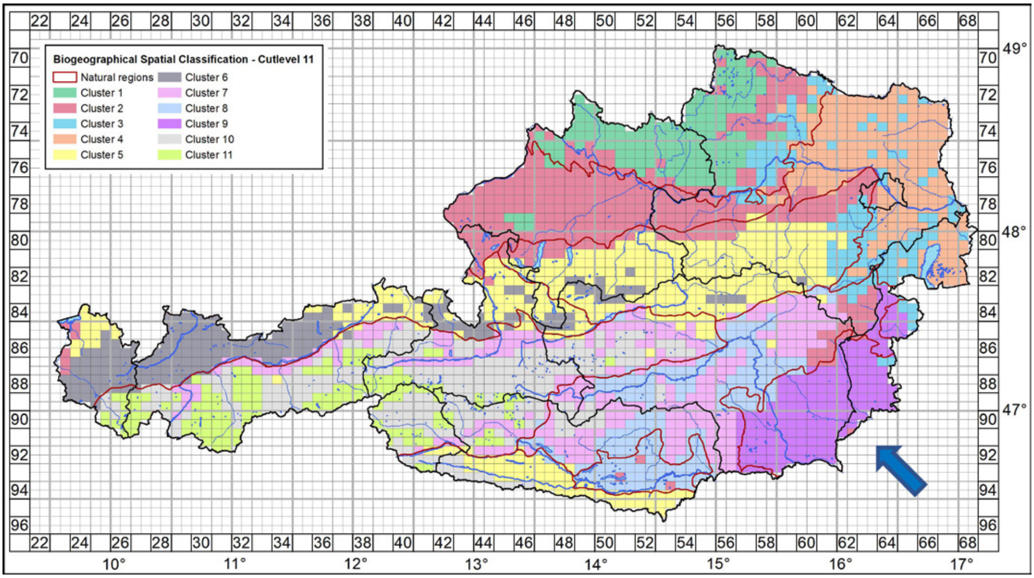

Fig. 12: Geographic delimitation of clusters identified at cutlevel 11 – differentiation of the Southeastern Foreland from the Klagenfurt Basin and the lower regions of the Central Alps. The blue arrow indicates the area in which cutlevels 11 and 10 (Fig. 11) differ. — **Abb. 12:** Cutlevel 11 – Trennung des Südöstlichen Vorlands vom Klagenfurter Becken und den tieferen Regionen der Zentralalpen. Der blaue Pfeil markiert den Bereich, in dem sich Cutlevel 11 und Cutlevel 10 (Abb. 11) unterscheiden.

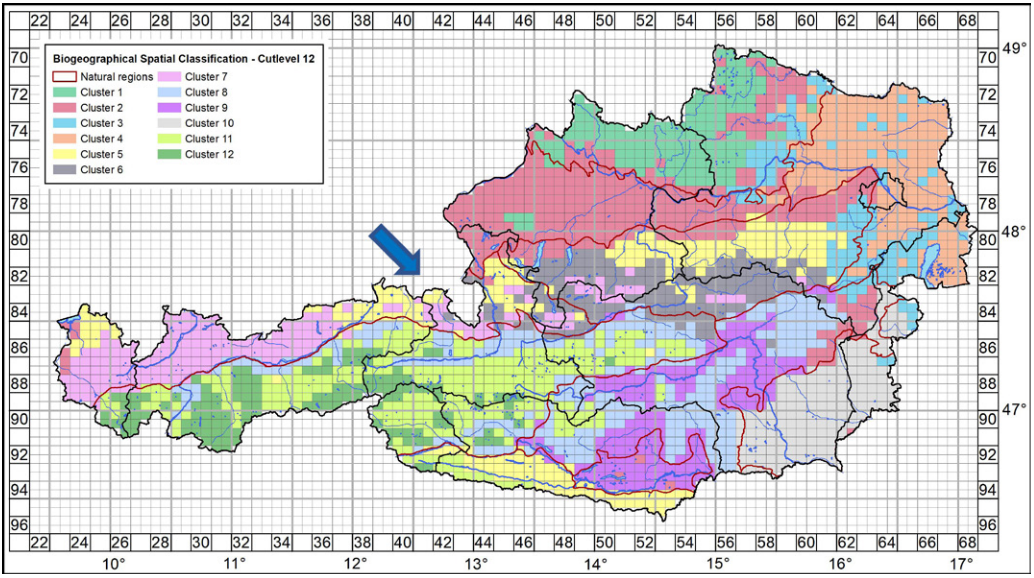

Fig. 13: Geographic delimitation of clusters identified at cutlevel 12 – further breakdown of the middle and eastern Northern Alps (regions with both, alpine and montane parts, in contrast to the almost purely montane regions). The blue arrow indicates the area in which cutlevels 12 and 11 (Fig. 12) differ. — **Abb. 13:** Geographische Abgrenzung der identifizierten Cluster auf Cutlevel 12 – weitere Unterteilung der mittleren und östlichen Nordalpen (Anteile mit alpinen wie auch montanen Anteilen gegenüber den vorwiegend montanen Regionen). Der blaue Pfeil markiert den Bereich, in dem sich Cutlevel 12 und Cutlevel 11 (Abb. 12) unterscheiden.

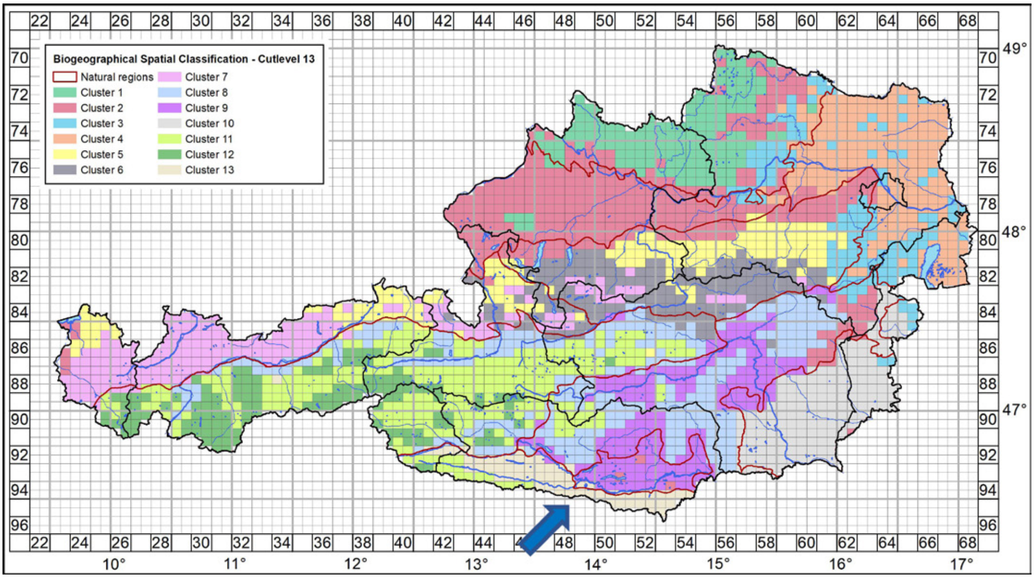

Fig. 14: Geographic delimitation of clusters identified at cutlevel 13 – differentiation of the Southern Calcareous Alps from corresponding regions of the Northern Alps). The blue arrow indicates the area in which cutlevels 13 and 12 (Fig. 13) differ. — **Abb. 14:** Geographische Abgrenzung der identifizierten Cluster auf Cutlevel 13 – Trennung der Südlichen Kalkalpen von korrespondierenden Teilen der Nordalpen. Der blaue Pfeil markiert den Bereich, in dem sich Cutlevel 13 und Cutlevel 12 (Abb. 13) unterscheiden.

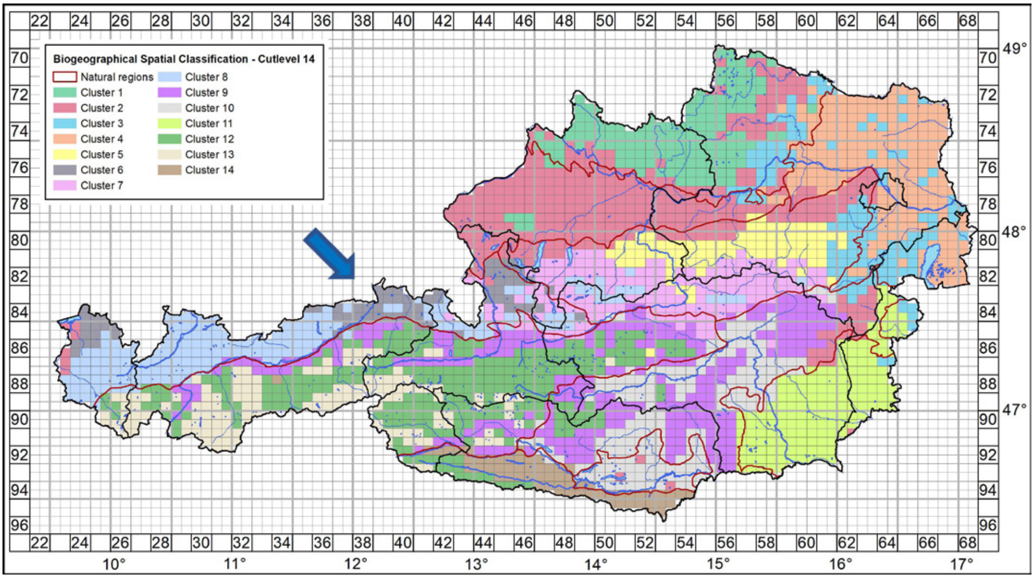

Fig. 15: Geographic delimitation of clusters identified at cutlevel 14 – distinction of the montane regions and valleys in the middle and western Northern Alps from the Northeastern Pre-Alps. The blue arrow indicates the area in which cutlevels 14 and 13 (Fig. 14) differ. — **Abb. 15:** Geographische Abgrenzung der identifizierten Cluster auf Cutlevel 14 – Trennung der montanen Regionen und Täler der mittleren und westlichen Nordalpen von den Nordöstlichen Voralpen. Der blaue Pfeil markiert den Bereich, in dem sich Cutlevel 14 und Cutlevel 13 (Abb. 14) unterscheiden.

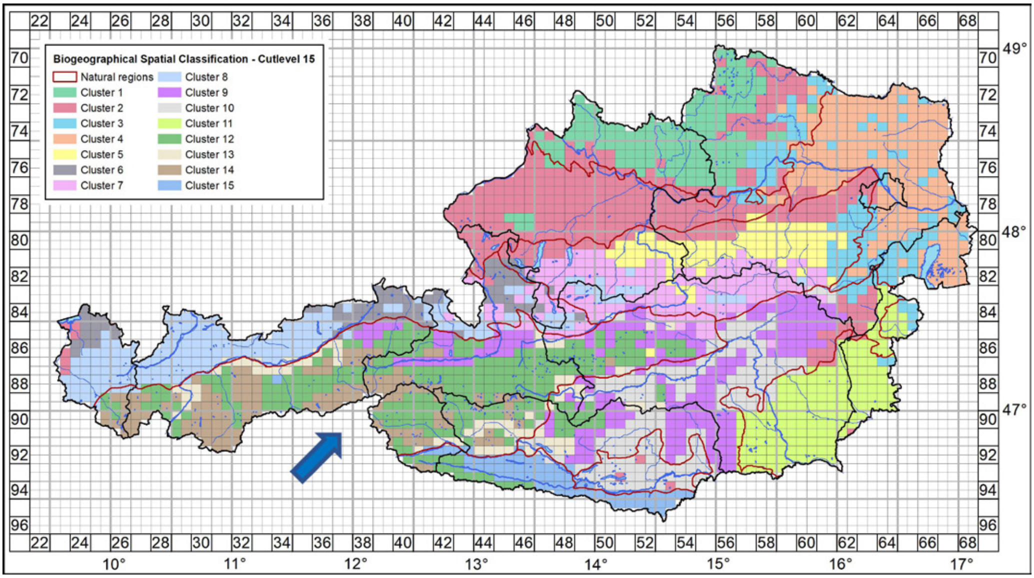

Fig. 16: Geographic delimitation of clusters identified at cutlevel 15 – distinction of inner-alpine valleys with dry climate. The blue arrow indicates the area in which cutlevels 15 and 14 (Fig. 15) differ. — **Abb. 16:** Geographische Abgrenzung der identifizierten Cluster auf Cutlevel 15 – Abtrennung inneralpiner Täler mit trockenem Klima. Der blaue Pfeil markiert den Bereich, in dem sich Cutlevel 15 und Cutlevel 14 (Abb. 15) unterscheiden.

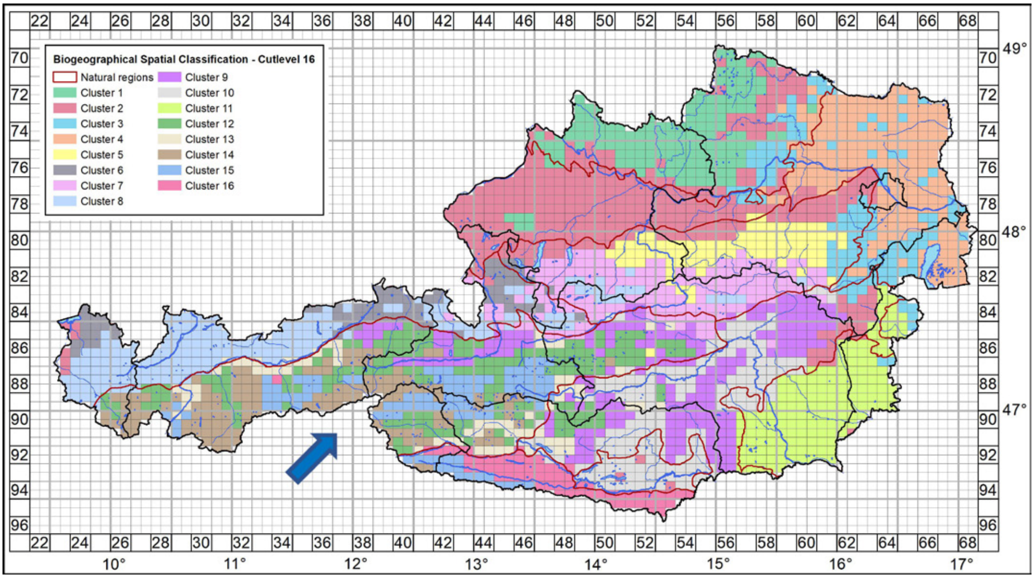

Fig. 17: Geographic delimitation of clusters identified at cutlevel 16 – further differentiation of the high-mountain part of the Central Alps into areas with uniformly acidic bedrock and areas with, at least partly, intermediate to alkaline bedrock. The blue arrow indicates the area in which cutlevels 16 and 15 (Fig. 16) differ. — **Abb. 17:** Geographische Abgrenzung der identifizierten Cluster auf Cutlevel 16 – weitere Unterteilung des Hochgebirgsanteils der Zentralalpen in Bereiche mit einheitlich saurem Substrat und Bereiche mit wenigstens teilweise intermediärem bis basischem Substrat. Der blaue Pfeil markiert den Bereich, in dem sich Cutlevel 16 und Cutlevel 15 (Abb. 16) unterscheiden.

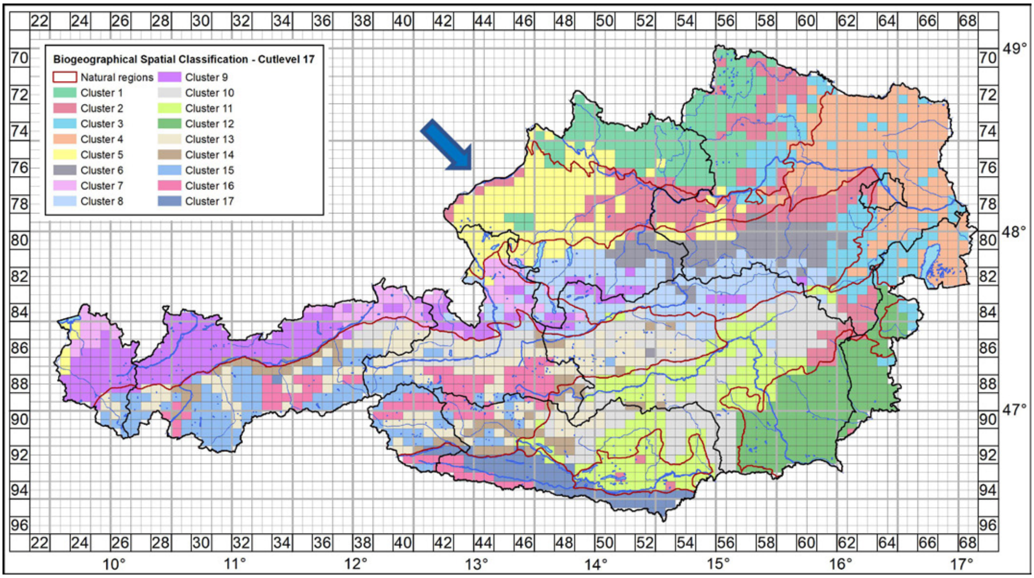

Fig. 18: Geographic delimitation of clusters identified at cutlevel 17 – differentiation of the western part of the Northern Foreland from parts of Traunviertel, and Mostviertel, the flysch part of Wienerwald, and the lower regions of Waldviertel. The blue arrow indicates the area in which cutlevels 17 and 16 (Fig. 17) differ. — **Abb. 18:** Geographische Abgrenzung der identifizierten Cluster auf Cutlevel 17 – Trennung des westlichen Teils des Nördlichen Vorlands von Anteilen des Traunviertels und Mostviertels sowie vom Flysch-Wienerwald und den niedrigeren Anteilen des Waldviertels. Der blaue Pfeil markiert den Bereich, in dem sich Cutlevel 17 und Cutlevel 16 (Abb. 17) unterscheiden.

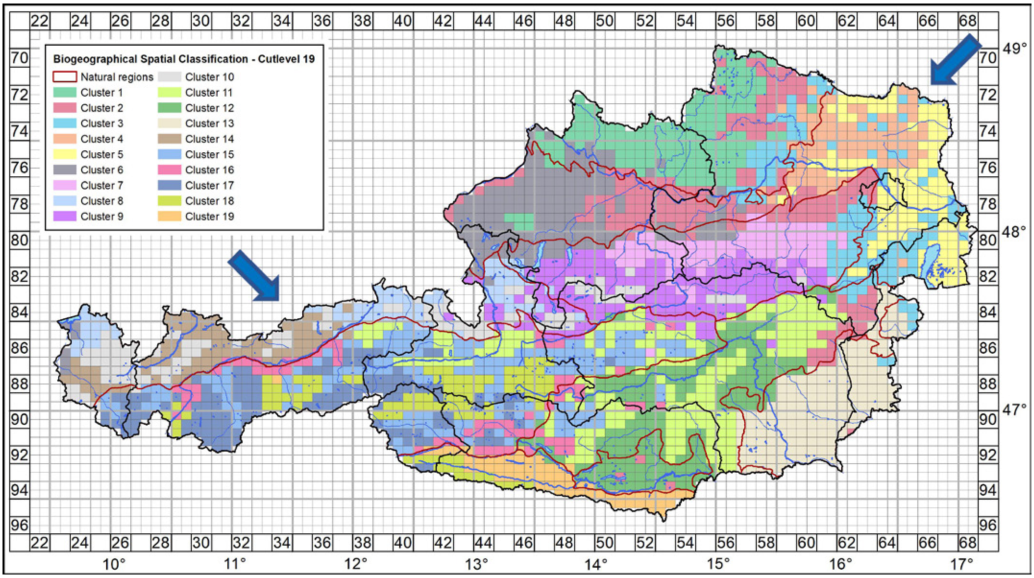

Fig. 19: Geographic delimitation of clusters identified at cutlevel 19 – Further differentiation of the middle and the western Northern Alps, and of the Pannonian region in plains and lower hillsides. The blue arrows indicate the areas in which cutlevels 19 and 17 (Fig. 18) differ. — **Abb. 19:** Geographische Abgrenzung der identifizierten Cluster auf Cutlevel 19 – weitere Untergliederung der mittleren und westlichen Nordalpen, sowie der Pannonischen Region in Ebenen und niedrige Hügelländer. Die blauen Pfeile markieren die Bereiche, in denen sich Cutlevel 19 und Cutlevel 17 (Abb. 18) unterscheiden.

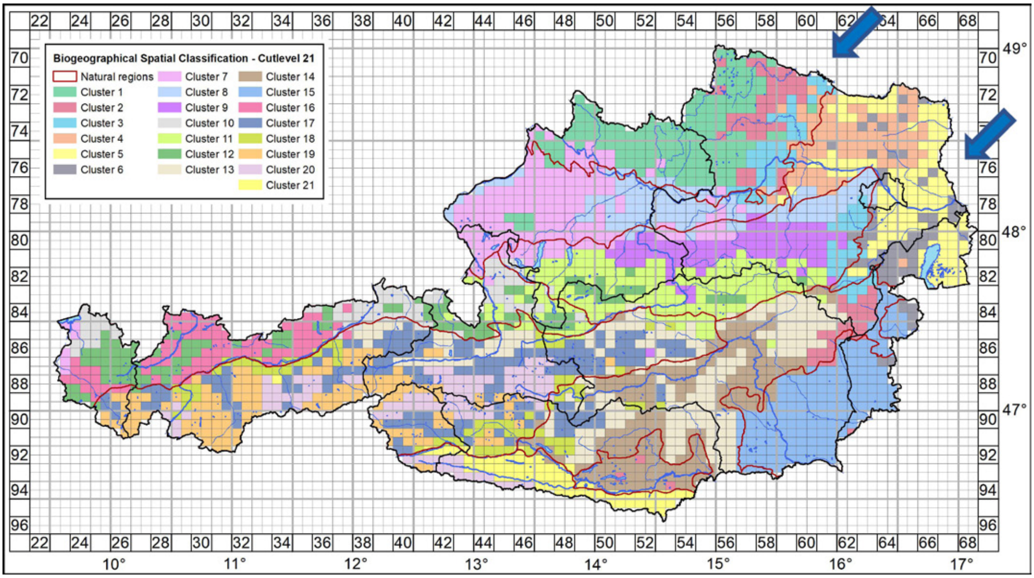

Fig. 20: Geographic delimitation of clusters identified at cutlevel 21 – separation of the lower regions of Waldviertel from the eastern parts of the Northern Foreland and the flysch part of Wienerwald. The blue arrows indicate the areas in which cutlevels 21 and 19 (Fig. 19) differ. — **Abb. 20:** Geographische Abgrenzung der identifizierten Cluster auf Cutlevel 21 – Trennung der niedrigeren Anteile des Waldviertels von den östlichen Teilen des Nördlichen Vorlands und dem Flysch-Wienerwald. Die blauen Pfeile markieren die Bereiche, in denen sich Cutlevel 21 und Cutlevel 19 (Abb. 19) unterscheiden.

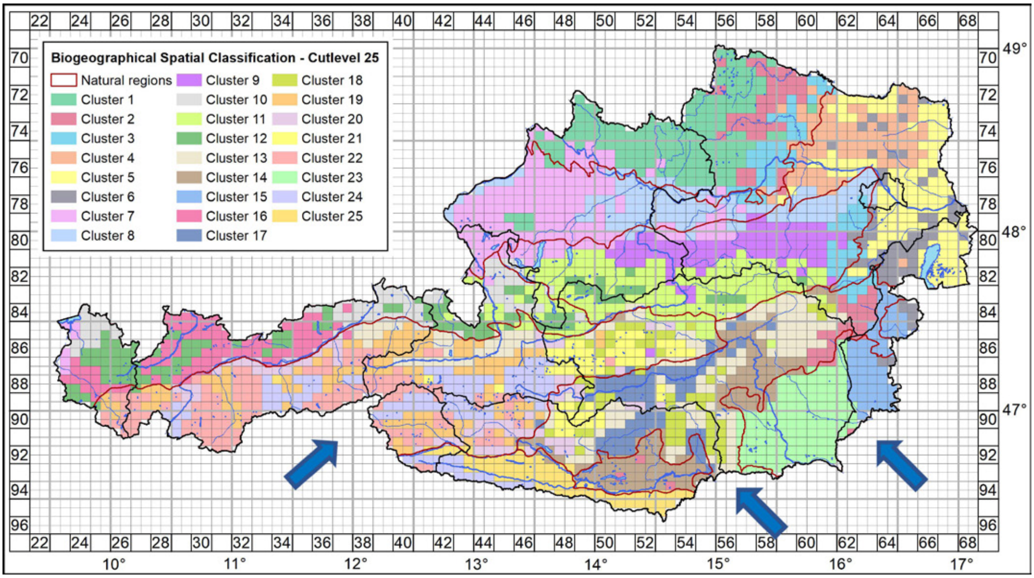

Fig. 21: Geographic delimitation of clusters identified at cutlevel 25 – division of the Southeastern Foreland into the Styrian hillside (Steirisches Hügelland) and the hillside parts of South and Middle Burgenland. Further differentiation of the eastern Central Alps. The blue arrows indicate the areas in which cutlevels 25 and 21 (Fig. 20) differ. — **Abb. 21:** Geographische Abgrenzung der identifizierten Cluster auf Cutlevel 25 – Teilung des Südöstlichen Vorlands in das Steirische Hügelland einerseits und den Großteil der Süd- und Mittelburgenländischen Hügelländer andererseits. Die blauen Pfeile markieren die Bereiche, in denen sich Cutlevel 25 und Cutlevel 21 (Abb. 20) unterscheiden.

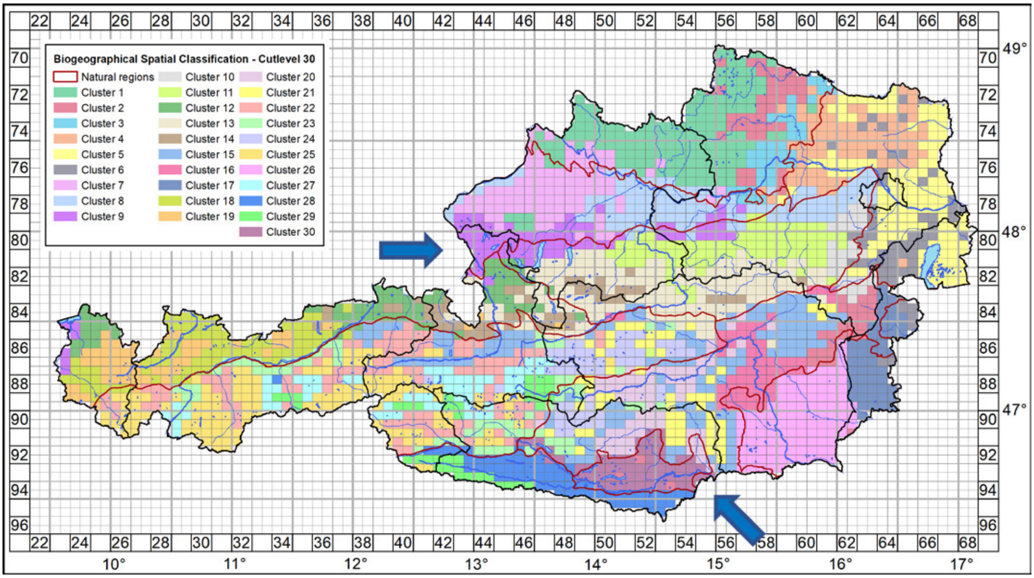

Fig. 22: Geographic delimitation of clusters identified at cutlevel 30 – distinction of the transition area from the Northern Alps to the Northern Foreland (western Flysch- and Moraine belt), differentiation of the Klagenfurt Basin from other regions. The blue arrows indicate the areas in which cutlevels 30 and 25 (Fig. 21) differ. — **Abb. 22:** Geographische Abgrenzung der identifizierten Cluster auf Cutlevel 30 – Abtrennung des Übergangsgebiets zwischen Nordalpen und Nördlichem Vorland (Flysch- und Moränengürtel) als eigene Region; Trennung des Klagenfurter Beckens von anderen Regionen. Die blauen Pfeile markieren die Bereiche, in denen sich Cutlevel 30 und Cutlevel 25 (Abb. 21) unterscheiden.

hills already at cutlevel 8. Also, the eastern part of the Northern Granite and Gneiss Highland was further differentiated at cutlevel 10. The Hausruck, an upland within the Northern Prealpine Foreland, was assigned to the Northern Granite and Gneiss Highland. The Klagenfurt Basin was outlined as a region by its own only at cutlevel 29. The Southern Alps were differentiated from the Northern Calcareous Alps at cutlevel 13, except the Austrian part of the Carnic Alps (Karnische Alpen) and the adjoining Lesachtal, which were assigned to the Central Alps (also at cutlevel 30). The lowlands of Vorarlberg (Rhine valley/Rheintal, Lake Constance/Bodensee) was assigned to the Northern Prealpine Foreland. In general, the Northern Alps and the Central Alps were more finely differentiated.

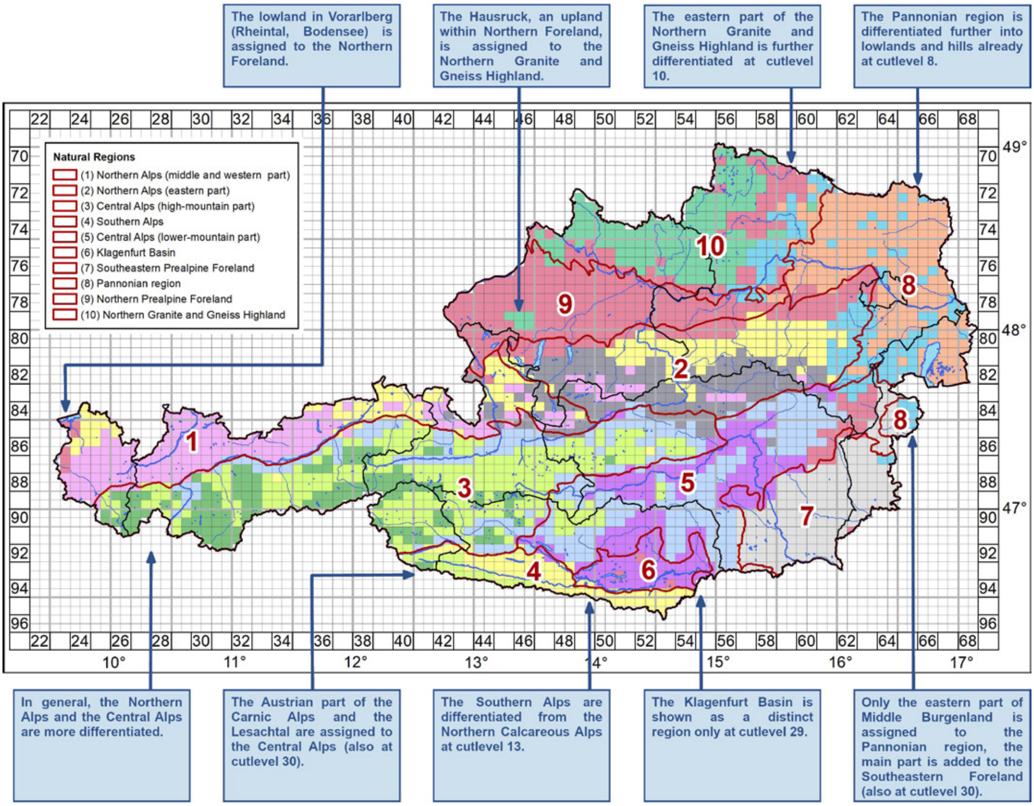

Fig. 23: Comparison of the results at cutlevel 12 with the natural landscape classification by Sauberer & Grabherr (1995a). — **Abb. 23:** Vergleich der Ergebnisse auf Cutlevel 12 mit der Naturraumklassifikation von Sauberer & Grabherr (1995a).

Conclusions

The spatial classification of Austria by vascular plant distribution data reflects different factors, the most important being altitude, geology, and climate. Pertaining to altitude, planar to montane regions were differentiated from subalpine to nival regions at the topmost cutlevel. Moreover, differentiations of biogeographical regions at higher cutlevels were based on altitude, for example, the differentiation of the Pannonian region into plains and hillsides. Climate and geology play an important role in the pedogenesis, and, therefore, are crucial factors for the biogeographical classification, such as the differentiation of the Northern and Southern Calcareous Alps from the Central Alps with predominantly acidic substrates. A further example of the important role of the regional climate is the separation of the Pannonian region from the other lower regions at a very high cutlevel. In general, smaller clusters are formed due to varied topography of an area (e. g. valleys in the mountains), which strongly applies to the alpine region.

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Electronic Supplement

The following data is provided within the electronic supplement:
Fig. S1: Cluster dendrogram based on Ward method and Euclidean distance. Blue rectangles indicate clusters at cutlevel 25.
Fig. S2: Cluster dendrogram based on Complete Linkage method and Euclidean distance. Blue rectangles indicate clusters at cutlevel 25.
Fig. S3: Cluster dendrogram based on Complete Linkage method and Jaccard index. Blue rectangles indicate clusters at cutlevel 25.
Fig. S4: Cluster dendrogram based on Complete Linkage method and Dice index. Blue rectangles indicate clusters at cutlevel 25.
Fig. S5: Geographic delimitation of clusters identified at cutlevel 25 based on Ward method and Euclidean distance.
Fig. S6: Geographic delimitation of clusters identified at cutlevel 25 based on Complete Linkage and Euclidean distance.
Fig. S7: Geographic delimitation of clusters identified at cutlevel 25 based on Complete Linkage method and Jaccard index.
Fig. S8: Geographic delimitation of clusters identified at cutlevel 25 based on Complete Linkage method and Dice index.
Fig. S9: NbClust diagram, Krzanowski and Lai Index (Ward method, Euclidean distance).

The electronic supplement is accessible under the following links:
https://doi.org/10.5281/zenodo.5821417
https://www.zobodat.at/pdf/NEIL_12_S1-S6.pdf

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