

A Floristic–ecological classification of gorse scrub communities with *Echinospartum ibericum* (Fabaceae) in the Iberian Peninsula

Íñigo Pulgar Sañudo 

Galiza Verde Foundation. Parque Empresarial de Pazos, E-15917 Padrón, A Coruña, Spain.
E-mail: inigo.pulgar@gmail.com

José Manuel Herrera Rodríguez 

Department of Natural Environment, Technologies and Agrarian Services (TRAGSATEC).
Julián Camarillo 6B, E-28037 Madrid, Spain.
E-mail: herrera1988@hotmail.com

Abstract. We analysed 194 phytosociological relevés from *Echinospartum ibericum* scrub communities across the Iberian Peninsula. Classification and ordination of the relevés were performed using multivariate statistical analyses, yielding 13 groups comprising nine syntaxa (associations or subassociations), three variants, and one transitional unit. For each community, we documented the distribution, bioclimatic characteristics, diagnostic species, and phytosociological class affinities of the participating flora. Relevés taken at higher altitudes were enriched in species of the class *Junipero-Pinetea*, whereas those from lower altitudes were enriched in species of the class *Cytisetea*. However, of the 12 communities identified, *Cytisetea* species predominated in eight, *Festucetea* in two, *Calluno-Ulicetea* in one, and *Junipero-Pinetea* in one. A syntaxonomic scheme is presented in accordance with these results.

Keywords: vegetation classification, pulvinate scrub, hierarchical cluster analysis (HCA), non-metric multidimensional scaling (NMDS).

Introduction

Echinospartum (Spach) Fourr. —commonly known as ‘cambrión’, ‘friar’s cushion’, among other names— is a genus of gorse-like shrubs comprising five species, four of which are endemic to the Iberian Peninsula and one (*E. horridum*) shared between France and Spain. Two species grow on calcareous substrates (*E. horridum* and *E. boissieri*), whereas the remaining three (*E. albigicum*, *E. barnadesii* and *E. ibericum*) occur on siliceous soils in the western half of the Iberian Peninsula (Talavera, 1999). According to Aparicio et al. (2002), the three species on siliceous substrates may have arisen through population isolation following the cold phases of the Quaternary. All species inhabit xeric environments owing to the scarcity of soil within the crevices of large rocky outcrops, where they root. Such environments are widespread in Iberian mountains of Mediterranean and sub-Mediterranean type, where communities containing members of the genus are particularly localised. This study focuses on communities containing *E. ibericum* Rivas Mart., Sánchez-Mata & Sancho, the species with the largest distribution area—from Sierra Morena to Galicia—mainly on granite and quartzite substrates. Within its distribution area, it occupies elevations of 700–2200 m a.s.l. (Talavera, 1999). As a woody shrub, the species can be classified as a nanophanerophyte or a chamaephyte, often forming pulvinate growth in high-mountain environments. Following the biogeographical framework of Rivas-Martínez et al. (2017a), it is endemic to the Western Iberian Mediterranean Province, with incursions into the Eurosiberian Region. These communities are of high conservation interest, as they form part of habitat type 4090 under the Habitats Directive 92/43/EEC, are rich in endemic species of the siliceous rocky areas of the western Iberian Peninsula, and are mostly located within protected areas of the Natura 2000 network.

Previous syntaxonomic treatments

Communities dominated by *E. ibericum* have been studied for decades across mountainous areas of the Iberian Peninsula. Considering the Iberian *Echinospartum* communities as a whole, Rivas-Martínez et al. (2001) proposed a classification reflecting an altitudinal gradient. Subsequently, new syntaxa have been described (Cano et al., 2007; Vicente-Orellana & Galán de Mera, 2008;

González de Paz et al., 2012) and partial revisions of the *E. ibericum* and *E. barnadesii* communities have been made (Costa et al., 2003; Gavilán et al., 2011; Amor & Ávila, 2012). In this study, we provide new relevés from the north-western limit of the species' distribution and, together with those of González de Paz (2012) and Honrado (2003), incorporate them into the published dataset, with the aim of characterising *E. ibericum* communities using a phytosociological approach. Specifically, our objectives are: (1) to characterise *E. ibericum* communities from floristic and bioclimatic perspectives; and (2) to provide an updated syntaxonomic scheme for these communities, based on the European vegetation synthesis by Mucina et al. (2019).

Material and methods

Data sources and management.

The study comprised 194 relevés containing *E. ibericum*, which were conducted according to the Braun–Blanquet methodology (Braun–Blanquet, 1979; Figure 1). The dataset covered the western Iberian Peninsula, extending from Sierra Morena to Galicia and northern Portugal. Of these, 177 relevés were compiled from the literature (Table S1), and 17 were unpublished relevés from the north-western end of the species' distribution (Serra do Xurés) (Table 1). Only the relevés from the original tables of the syntaxa that included *E. ibericum* were incorporated into the analysis, as it is beyond the scope of this study to characterise biotopes without the occurrence of this species. At the taxonomic level, this study followed the nomenclature of *Flora Iberica* (Castroviejo et al., 1986–2021), not recognising the intraspecific taxa of *E. ibericum* (Talavera, 1999). Using the WorldClim database (Fick & Hijmans, 2017), with a spatial resolution of 1 km², the following bioclimatic indices were calculated for each relevé: thermicity index (It), annual ombrothermic index (Io), and continentality index (Ic); these indices were used to establish the bioclimatic units (Rivas-Martínez et al., 2017b). Relevés that lacked 1 × 1 km grid-square references were located as accurately as possible on the basis of the reported altitude and the descriptions provided in the published sources. Relevés located within the same grid-square were assigned the same mean values for each index.

Data analysis

The main vegetation types were identified through hierarchical cluster analysis (HCA) and non-metric multidimensional scaling (NMDS) ordination.

To conduct the HCA, vegetation cover values were transformed to the combined scale (van der Maarel, 1979). We then calculated the Hellinger distance matrix based on the species data (Legendre & Legendre, 2003; Borcard et al., 2011), which down-weights high abundances relative to low ones and avoids similarities arising from joint absences. We used this matrix to obtain floristic relationships between relevés and subsequently performed hierarchical clustering using Ward's minimum variance method (Ward, 1963).

The optimal number of clusters was determined using three separate analyses. The first analysis compared the dissimilarity matrix with the binary matrices of the successive partitions (Borcard et al., 2018). This technique compared the original dissimilarity matrix with binary matrices calculated by cutting the dendrogram at various levels. The second analysis calculated the average silhouette widths (Rousseeuw, 1987). Silhouette width is a measure of the degree to which an object belongs to its group, based on the average difference between that object and all objects in its own group, compared to the same measure calculated for the next-closest group. At each fusion level, the average silhouette width can be used as a measure of the quality of the partition (Rousseeuw quality index). The third method used was the species fidelity analysis (Borcard et al., 2018), which forms groups based on a set of diagnostic species, that is, species that are significantly more frequent and abundant in a specific group of sites. Specifically, the best partition maximises both (i) the sum of the indicator values and (ii) the proportion of clusters with significant indicator species. In this study, we used the IndVal index (Dufrêne & Legendre, 1997) with a significance threshold of $p \leq 0.01$.

Once the optimal number of clusters was established, a synoptic table analysis was carried out. Diagnostic species were defined as those with $\text{IndVal} \geq 0.4$ and $p \leq 0.01$, using the extension developed by De Cáceres et al. (2010b), which identifies indicator species for individual site groups and combinations of site groups. Constant species were defined as those that occur in $\geq 50\%$ of a cluster's relevés, and dominant species as those with cover $> 25\%$ in more than 50% of the relevés.

To visualize the relationships between the main groups of relevés, an NMDS ordination was carried out using the Hellinger distance in three dimensions ($k = 3$). Environmental variables were passively represented by vectors that maximised the linear correlation between each explanatory variable and the NMDS axes.

Spearman's rho correlation coefficient was used to evaluate pairwise correlations between bioclimatic indices and altitude. An affinity analysis of the groups for specific phytosociological classes was carried out. For this, the species present in each relevé were assigned to the corresponding phytosociological class using the catalogue of Rivas-Martínez et al. (2011). The percentages of phytosociological classes in each group were calculated by summing, for each relevé, the number of species assigned to each class.

Statistical analyses were performed with the 'vegan' (Oksanen et al., 2018) and 'indicpecies' (De Cáceres & Jansen, 2016) packages using the R software environment (R Core Team, 2018).

Results

Multivariate analysis-HCA

Across 194 phytosociological relevés, 189 vascular plant species were recorded. *E. ibericum* had a mean cover of 41%. The most frequent species co-occurring with *E. ibericum* ($> 25\%$ of relevés) were *Festuca yvesii* subsp. *summilusitana* (48%), *Avenella flexuosa* (37%), *Cytisus oromediterraneus* (36%), *Sedum brevifolium* (32%), *Helictochloa marginata* (29%) and *Erica arborea* (26%).

The HCA of the *E. ibericum* communities is shown in Figure 2. The analyses indicated 13 clusters from both the comparison of the dissimilarity matrix with binary matrices of successive partitions and the species-fidelity analysis, and 14 clusters from the average silhouette-width criterion.

After examining the two partitions from floristic and biogeographical perspectives, a 13-cluster solution was selected. This partition appears to reflect an altitudinal division into three main branches: clusters 1–6 at low-altitude sites (680–1600 m a.s.l.), clusters 7–10 at high-altitude sites (1637–2390 m a.s.l.), and clusters 11–13 at intermediate-altitude sites between the other two branches (1069–1640 m a.s.l.).

The 13 clusters exhibit distinctive floristic compositions with characteristic diagnostic species (exclusive or shared among clusters), as shown in the synoptic table (Table 2), together with constant and dominant species.

Physiognomically, all clusters, except 6, 9 and 11, are dominated by *E. ibericum*. Clusters 6 and 11 lack dominant species, whereas cluster 9 has *Juniperus communis* subsp. *alpina* as the sole dominant.

Multivariate analysis-NMDS

The NMDS (Figure 3) yielded a three-dimensional solution (final stress = 0.17) with linear and non-metric goodness-of-fit values of $R^2 = 0.795$ and 0.969, respectively. The 13 clusters detected by HCA were arranged along the main axes. Clusters 1–6 were opposed to clusters 7–10 along axis 1, while clusters 1 and 8–10 were separated from clusters 4–6 and 11–12 along axis 2. Axis 3 separated clusters 2, 3, 8, 9, and 12 from clusters 1 and 11.

The species with the highest positive correlations (> 0.4) with axis 1 were *Cytisus oromediterraneus*, *Avenella flexuosa*, *Neoschischkinia truncatula* subsp. *truncatula*, and *Arrhenatherum elatius*, whereas *Helictochloa*

marginata, *Cytisus multiflorus*, *Neoschischkinia truncatula* subsp. *durieui*, *Genista hystrix*, and *Pterospartum tridentatum* showed the highest negative correlations. On axis 2, *Festuca yvesii* subsp. *summilusitana* and *Sedum brevifolium* showed strong positive correlations (> 0.4), while no species showed a negative correlation on this axis. On axis 3, *Genista hystrix* and *Juniperus communis* subsp. *alpina* showed the highest positive correlations, whereas *Sedum brevifolium* showed the highest negative correlation.

Environmental factors

As shown by the vectors of environmental variables superimposed on the NMDS ordination (Figure 3; correlations > 0.4), axis 1 is positively correlated with altitude (Alt) and the annual ombrothermic index (Io) and negatively correlated with the thermicity index (It). Both Io and It are strongly correlated with Alt and partially correlated with the continentality index (Ic) (Figure S1). Clusters 7–10 comprise relevés taken at higher-altitude sites, whereas clusters 1–6 comprise those taken at lower-altitude sites. A similar pattern is also evident for Io. Axis 1 can be interpreted as a gradient of increasing Io and decreasing It. Axis 2 is positively correlated with Io and negatively with Ic and It. Clusters 11–12 comprise relevés with high Ic and It and low Io, whereas clusters 8–10 comprise relevés with low Ic and It and high Io. This axis can be interpreted as a gradient of increasing Io and decreasing Ic and It. Finally, axis 3 shows no significant correlations with the bioclimatic variables and does not reflect any gradient in the bioclimatic variables considered.

Syntaxonomic analysis

The proportional representation of diagnostic species belonging to phytosociological classes or subordinate syntaxa (Rivas-Martínez et al., 2011; Figure 4) shows that all clusters include species of the class *Cytisetea scopario-striati*, which is the dominant class in all clusters except clusters 1, 9, 10, and 12. In cluster 1, species of the class *Calluno-Ulicetea* predominate (19%); in cluster 9, those of the class *Junipero-Pinetea* predominate (30.6%); and in clusters 10 and 12, species of the class *Festucetea indigestae* predominate slightly (24.7% and 22.9%, respectively). In the remaining clusters, species of the class *Cytisetea* have the highest proportional representation, with the highest proportion (48.3%) in cluster 5.

Plant community description

On the basis of the statistical analyses presented above and the details provided in the synoptic table (Table 2), nine associations are recognised (clusters 1, 2–3, 4–6, 7 and 13, 8, 9, 10, 11 and 12; Figure 2). Three variants (clusters 3, 4 and 6) and one transitional unit (cluster 13) were identified within these nine associations. In cases where two clusters were merged into a single group, the values of diagnostic, constant and dominant species, as well as the syntaxonomy and bioclimatology, were recalculated.

***Festuco summilusitanae–Echinopartetum iberici* Costa Ten., Morla & Sáinz-Ollero, 1993, nom. corr. (cluster 1)**

[*Festuco graniticolae–Echinopartetum lusitanici*, Costa Ten., Morla & Sáinz-Ollero, in *Lazaroa* 13: 144, T. 1. 1993 (art. 43).] Taxonomic corrections: *Echinopartum ibericum* subsp. *pulviniformis* (Rivas Mart.) Rivas Mart., 1987, in *Lazaroa* 7: 111, should be *Echinopartum ibericum* Rivas Mart., Sánchez-Mata & Sancho; and *Festuca graniticola* Kerguelén & Morla, 1985, in *Anales Jard. Bot. Madrid* 42(1): 156, should be *Festuca yvesii* subsp. *summilusitana* (Franco & Rocha Afonso) Mart.-Sagarra & Devesa, in *Acta Bot. Malacitana* 46 (2021).

E. ibericum thorny gorse scrubs occur in the Supratemperate sub-Mediterranean belt of the NW of the Iberian Peninsula (Galicia, W Zamora, N of Portugal).

Exclusive diagnostic species: Not present.

Shared diagnostic species: *Festuca yvesii* subsp. *summilusitana*, *Helictochloa marginata*, *Neoschischkinia truncatula* subsp. *durieui*, *Sedum brevifolium*, *Pterospartum tridentatum* and *Ornithogalum concinnum*.

Constant species: *Sedum brevifolium*, *Festuca yvesii* subsp. *summilusitana*, *Neoschischkinia truncatula* subsp. *durieui*, *Helictochloa marginata* and *Pterospartum tridentatum*.

Dominant species: *Echinopartum ibericum* (mean cover = 35%).

Syntaxonomy: This association is dominated by species of the class *Calluno-Ulicetea* (19%), followed by those of the classes *Stipo giganteae-Agrostietea castellanæ* (14.9%), *Festucetea indigestae* (11.8%), and *Cytisetea* (10.5%).

Synchorology: This association is distributed in the NW of the Iberian Peninsula (Galicia, W Zamora, N of Portugal), with an altitudinal range of 960–1600 m a.s.l. North Lusitania Sierran Sector (Peneda and Xurés Sierras District), Lusitanian Douro Sector (Chaves–Verín and Bragança Districts), Bierzo and Sanabria Sector (Queixa Sierran District and W of Zamora–Sanabria District).

Bioclimatology: Supratemperate sub-Mediterranean bioclimatic belt, with an ombrotype ranging from upper subhumid to lower hyperhumid and continentality from pronounced semihyperoceanic to pronounced euoceanic.

***Genisto hystricis-Echinopartum iberici* Navarro & Valle, 1983, corr. Rivas-Martínez, 2011 (clusters 2 and 3)**

E. ibericum gorse scrubs with *Genista hystris* occur in the upper Mesomediterranean and lower Supramediterranean belts of the NW of the Iberian Peninsula (Zamora, E and NE Bragança).

***Genisto hystricis-Echinopartum iberici* F. Navarro & C. Valle, 1983, corr. Rivas-Martínez, 2011 (Typical) (cluster 2)**

E. ibericum thorny gorse scrubs of the upper Mesomediterranean belt of the Bierzo and Sanabria Sector (Maragatería, Zamora–Sanabria Districts), located below 810 m a.s.l.

Exclusive diagnostic species: *Leucanthemopsis pulverulenta*.

Shared diagnostic species: *Genista hystris*, *Digitalis thapsi*, *Neoschischkinia truncatula* subsp. *durieui* and *Ornithogalum concinnum*.

Constant species: *Genista hystris*, *Leucanthemopsis pulverulenta*, *Ornithogalum concinnum*, *Cytisus scoparius*, *Neoschischkinia truncatula* subsp. *durieui*, *Stipa gigantea* and *Genista florida*.

Dominant species: *Echinopartum ibericum* (mean cover = 58%).

Syntaxonomy: Association in which species of the classes *Cytisetea* (39.1%) and *Festucetea indigestae* (19.6%) dominate.

Synchorology: Association distributed in the province of Zamora, with an altitudinal range of 700–810 m a.s.l. Bierzo and Sanabria Sector (Maragatería, Cabrera–Montes de León, and Zamora–Sanabria Districts).

Bioclimatology: Upper Mesomediterranean to lower Supramediterranean bioclimatic belts, with a lower subhumid ombrotype and a marked euoceanic level of continentality.

***Genisto hystricis-Echinopartum iberici* var. with *Dianthus laricifolius* subsp. *merinoi* (cluster 3)**

E. ibericum gorse scrubs occur above 870 m a.s.l. at the boundary between the Bierzo and Sanabria Sector (Zamora–Sanabria District) and Salamanca Sector (High Salamanca District).

Exclusive diagnostic species: *Dianthus laricifolius* subsp. *merinoi*.

Shared diagnostic species: *Genista hystris*, *Helictochloa marginata* and *Pterospartum tridentatum*.

Constant species: *Genista hystris*, *Helictochloa marginata* and *Pterospartum tridentatum*.

Dominant species: *Echinopartum ibericum* (mean cover = 31%).

Syntaxonomy: Variant in which species of the classes *Cytisetea* (23.9%) and *Calluno-Ulicetea* (23.2%) dominate, followed at a distance by species of the classes *Festucetea indigestae* (11.3%), *Tuberarietea* (10.6%) and *Stipo giganteae–Agrostietea castellanae* (9.9%).

Synchorology: Variant located in the province of Zamora, with an altitudinal range of 870–1370 m a.s.l. Bierzo and Sanabria Sector (Zamora–Sanabria District) and Salamanca Sector (NE High Salamanca District).

Bioclimatology: Supramediterranean bioclimatic belt with a lower subhumid to upper humid ombrotype and continentality ranging from attenuated semihyperoceanic to pronounced euoceanic.

***Echinospartetum iberici* Rivas-Martínez, 1974, corr. Rivas-Martínez & Sánchez-Mata, 2002 (clusters 4, 5, and 6)**

E. ibericum gorse scrubs occur in the Supratemperate sub-Mediterranean and Supramediterranean belts of the CW of the Iberian Peninsula. Our results indicate the presence of two variants:

***Echinospartetum iberici* (Typical) (cluster 5)**

Exclusive diagnostic species: Not present.

Shared diagnostic species: *Cytisus multiflorus* and *Helictochloa marginata*.

Constant species: *Cytisus multiflorus*, *Genista cinerascens* *Digitalis thapsi* and *Neoschischkinia truncatula* subsp. *duriei*.

Dominant species: *Echinospartum ibericum* (mean cover = 55%).

Syntaxonomy: Association dominated by species of the class *Cytisetea* (48.3%), followed by the class *Calluno-Ulicetea* (12.4%).

Synchorology: This association is widely distributed in the CW Iberian Peninsula, with an altitudinal range of 680–980 m a.s.l. Salamanca Sector (High Salamanca District), Lusitano-Duriense Sector (Beira Norte District), and Montemuro and Estrela Sierras Sector (Estrela Sierran and Guarda Districts).

Bioclimatology: Supratemperate sub-Mediterranean and Supramediterranean bioclimatic belts, with a lower subhumid to lower humid ombrotype and continentality from attenuated semihyperoceanic to attenuated euoceanic.

***Echinospartetum iberici* var. with *Halimium lasianthum* subsp. *alyssoides* (cluster 6)**

Exclusive diagnostic species: Not present.

Shared diagnostic species: *Cytisus multiflorus* and *Helictochloa marginata*.

Constant species: *Cytisus multiflorus*, *Halimium lasianthum* subsp. *alyssoides*, *Arenaria querioides* and *Helictochloa marginata*.

Dominant species: Not present.

Syntaxonomy: Variant in which species of the class *Cytisetea* dominate (33%), followed by the class *Calluno-Ulicetea* (31.9%).

Synchorology: Variant based on relevés from the Sierra de Gata, with an altitudinal range of 850–1320 m a.s.l. Salamanca Sector (High Salamanca District).

Bioclimatology: Supratemperate sub-Mediterranean and Supramediterranean bioclimatic belts, with a lower subhumid to lower humid ombrotype and continentality from attenuated semihyperoceanic to attenuated euoceanic.

***Echinospartetum iberici* var. with *Erica arborea* (cluster 4)**

Exclusive diagnostic species: Not present.

Shared diagnostic species: *Halimium lasianthum* subsp. *alyssoides*, *Helictochloa marginata*, *Neoschischkinia truncatula* subsp. *duriei* and *Pteridium aquilinum*.

Constant species: *Halimium lasianthum* subsp. *alyssoides*, *Helictochloa marginata* and *Erica arborea*.

Dominant species: *Echinopartum ibericum* (mean cover = 60%).

Syntaxonomy: Variant dominated by species of the class *Cytisetea* (35.6%), followed by the class *Calluno-Ulicetea* (23.7%) and the class *Stipo giganteae–Agrostietea castellanae* (15.3%).

Synchorology: Variant based on relevés from the Serra da Estrela, with an altitudinal range of 1050–1600 m a.s.l. Montemuro and Estrela Sierras Sector (Estrela Sierran and Guarda Districts).

Bioclimatology: Supratemperate sub-Mediterranean bioclimatic belt, with an ombrotype ranging from upper subhumid to lower hyperhumid and continentality ranging from attenuated semihyperoceanic to pronounced euoceanic.

***Cytiso oromediterranei–Echinopartum pulviniformis* Rivas-Martínez et al., 1987 (clusters 7 and 13)**

“Piorno serrano” (*Cytisus oromediterraneus*) brooms with *E. ibericum* in the Oromediterranean and upper Supramediterranean belts of the Central Range. The association comprises two clusters: cluster 7 corresponds to the typical association and occurs in the Oromediterranean belt from the W of the Sierra de Gredos to the Peña de Francia, and cluster 13, which groups the communities of the upper Supramediterranean belt of these same mountains, including the highest-altitude relevés from the Sierra de Gata.

Exclusive diagnostic species: Not present.

Shared diagnostic species: *Cytisus oromediterraneus*, *Avenella flexuosa*, *Neoschischkinia truncatula* subsp. *truncatula*, *Festuca yvesii* subsp. *summilusitana* and *Arrhenatherum elatius*.

Constant species: *Avenella flexuosa*, *Cytisus oromediterraneus*, *Neoschischkinia truncatula* subsp. *truncatula* and *Festuca yvesii* subsp. *summilusitana*.

Dominant species: *Echinopartum ibericum* (mean cover = 49%).

Syntaxonomy: Association dominated by species of the class *Cytisetea* (23.6%), with a substantial contribution from the class *Festucetea indigestae* (18.1%) and, to a lesser extent, the classes *Stipo giganteae–Agrostietea castellanae* (13.5%), *Thlaspietea rotundifolii* (10.7%) and *Junipero-Pinetea* (9.7%).

Synchorology: This association occurs in the highest areas of the mountain ranges of Tormantos, Gata, Peña de Francia, Béjar, and W Gredos (cluster 7: 1650–2390 m a.s.l.; cluster 13: 1320–1640 m a.s.l.). Béjar and Gredos Sierras Sector (Tormantos Sierran and Béjar Sierran Districts) and Salamanca Sector (Batuecas and Malcata Sierran District).

Bioclimatology: Orotemperate sub-Mediterranean, upper Supratemperate sub-Mediterranean, and upper Supramediterranean bioclimatic belts, with a lower subhumid to lower hyperhumid ombrotype and continentality from attenuated semihyperoceanic to attenuated euoceanic.

***Teucro salviastrum–Echinopartum pulviniformis* Rivas-Martínez, 1974, corr. 1981 (cluster 8)**

Gorse scrubs with *E. ibericum* and *Teucrium salviastrum* in the sub-Mediterranean Supra-Orotemperate belts on the summits of the Serra da Estrela (Portugal).

Exclusive diagnostic species: *Phalacrocarpum oppositifolium* subsp. *oppositifolium* and *Teucrium salviastrum*.

Shared diagnostic species: *Juniperus communis* subsp. *alpina*, *Cytisus oromediterraneus*, *Avenella flexuosa* and *Festuca yvesii* subsp. *summilusitana*.

Constant species: *Phalacrocarpum oppositifolium* subsp. *oppositifolium*, *Juniperus communis* subsp. *alpina*, *Teucrium salviastrum*, *Avenella flexuosa* and *Erica arborea*.

Dominant species: *Echinopartum ibericum* (mean cover = 31%).

Syntaxonomy: Association dominated by species of the class *Cytisetea* (30%), with a large contribution from the classes *Junipero-Pinetea* (19.1%) and *Stipo giganteae–Agrostietea castellanae* (19.1%).

Synchorology: Exclusive to the Serra da Estrela, with an altitudinal range of 1650–1970 m a.s.l. Montemuro and Estrela Sierras Sector (Estrela Sierran District).

Bioclimatology: Sub-Mediterranean Supra-Orotemperate bioclimatic belts, with a lower humid to lower hyperhumid ombrotype and a markedly attenuated semihyperoceanic level of continentality.

Genisto sanabrensis–Juniperetum alpinae F. Prieto, 1983, corr. Rivas-Martínez, 2011, ***echinospartetosum iberici*** Penas et al., 1990 (**cluster 9**)

Juniper thickets with *Genista sanabrensis* and *E. ibericum* in the sub-Mediterranean Orotemperate belt of the Bierzo and Sanabria Sector.

Exclusive diagnostic species: *Genista sanabrensis*.

Shared diagnostic species: *Juniperus communis* subsp. *alpina*, *Avenella flexuosa*, *Festuca yvesii* subsp. *summilusitana* and *Pterospartum tridentatum*.

Constant species: *Genista sanabrensis*, *Juniperus communis* subsp. *alpina*, *Festuca yvesii* subsp. *summilusitana*, *Pterospartum tridentatum* and *Avenella flexuosa*.

Dominant species: *Juniperus communis* subsp. *alpina* (mean cover = 42%).

Syntaxonomy: Association dominated by species of the class *Junipero-Pinetea* (30.6%), followed by the classes *Festucetea indigestae* (18.4%), *Calluno-Ulicetea* (16.6%) and *Cytisetea* (12.2%).

Synchorology: Subassociation that develops at the intersection among the Segundera, Cabrera, and Eixe mountain ranges (1830–1870 m a.s.l.). Bierzo and Sanabria Sector (Cabrera and Montes de León District).

Bioclimatology: Lower Orotemperate belt, with an upper humid to lower hyperhumid ombrotype and an attenuated semihyperoceanic level of continentality.

Armerio ciliatae–Echinospartetum iberici González de Paz, 2012 (**cluster 10**)

E. ibericum gorse scrubs with *Armeria ciliata* in the sub-Mediterranean Supra-Orotemperate belts in the Sierra de La Cabrera (Zamora).

Exclusive diagnostic species: *Armeria ciliata*.

Shared diagnostic species: *Cytisus oromediterraneus*, *Avenella flexuosa*, *Festuca yvesii* subsp. *summilusitana*, *Neoschischkinia truncatula* subsp. *durieui* and *Sedum brevifolium*.

Constant species: *Armeria ciliata*, *Festuca yvesii* subsp. *summilusitana*, *Sedum brevifolium* and *Avenella flexuosa*.

Dominant species: *Echinospartum ibericum* (mean cover = 60%).

Syntaxonomy: Species of the classes *Festucetea indigestae* (24.7%) and *Cytisetea* (22.1%) dominate in this association.

Synchorology: This association is exclusive to the Sierra de La Cabrera (Zamora), with an altitudinal range of 1637–1940 m a.s.l. Bierzo and Sanabria Sector (Zamora–Sanabria District).

Bioclimatology: Sub-Mediterranean Supra-Orotemperate bioclimatic belts, with a lower humid to lower hyperhumid ombrotype and continentality ranging from marked semihyperoceanic to marked euoceanic.

Genisto cinerascens–Adenocarpetum argyrophylli Vicente-Orellana & Galán, 2008, subass. ***echinospartetosum iberici*** Vicente-Orellana & Galán, 2008 (**cluster 11**)

Brooms of *Genista cinerascens* with *Adenocarpus argyrophyllus* and *E. ibericum* in the Supramediterranean belt of the southern half of the Iberian Peninsula (Cáceres, Toledo, and Ciudad Real).

Exclusive diagnostic species: *Adenocarpus argyrophyllus*, *Dianthus lusitanicus*, *Halimium ocymoides* and *Quercus rotundifolia*.

Shared diagnostic species: *Sedum brevifolium* and *Arrhenatherum elatius*.

Constant species: *Dianthus lusitanicus*, *Adenocarpus argyrophyllus*, *Arrhenatherum elatius*, *Halimium ocymoides*, *Juniperus oxycedrus* subsp. *badia* (lagunae), *Quercus rotundifolia* and *Sedum brevifolium*.

Dominant species: Not present.

Syntaxonomy: In this association, species of the class *Cytisetea* dominate (19.8%), followed by the classes *Quercetea ilicis* (11.1%) and *Phagnalo-Rumicetea* (11.1%).

Synchorology: Subassociation distributed throughout the mountain ranges of Las Villuercas, Madrona, and Montes de Toledo, with an altitudinal range of 1,069–1,590 m a.s.l. Oretano Sector (Villuercas Sierran and Eastern Montes of Toledo Districts) and Mariánica Range Sector (East Mariánica District).

Bioclimatology: Supramediterranean bioclimatic belt, with a lower dry to upper subhumid ombrotype and continentality from attenuated euoceanic to attenuated semicontinental.

Cytiso oromediterranei–Genistetum cinerascens Rivas-Martínez, 1970, var. with ***Echinopartum ibericum*** Sardinero, 2004 (cluster 12)

Cytisus oromediterraneus and *Genista cinerascens* brooms with *E. ibericum* in the Supramediterranean belt of the Sistema Central.

Exclusive diagnostic species: *Euphorbia oxyphylla*, *Thymus zygis*, *Corynephorus canescens*, *Lavandula pedunculata*, *Cytisus scoparius*, *Adenocarpus complicatus*, *Armeria trasmontana*, *Centaurea alba*, *Genista tournefortii*, *Quercus pyrenaica* and *Festuca elegans*.

Shared diagnostic species: *Pteridium aquilinum*, *Genista cinerascens*, *Digitalis thapsi*, *Arenaria querioides*, *Neoschischkinia truncatula* subsp. *truncatula* and *Cytisus oromediterraneus*.

Constant species: *Cytisus oromediterraneus*, *Corynephorus canescens*, *Genista cinerascens*, *Lavandula pedunculata*, *Cytisus scoparius*, *Euphorbia oxyphylla*, *Thymus zygis*, *Quercus pyrenaica*, *Festuca elegans*, *Adenocarpus complicatus*, *Armeria trasmontana*, *Centaurea alba*, *Genista tournefortii*, *Digitalis thapsi*, *Arenaria querioides*, *Neoschischkinia truncatula* subsp. *truncatula*, *Agrostis castellana* and *Jasione sessiliflora*.

Dominant species: *Echinopartum ibericum* (mean cover = 36%).

Syntaxonomy: Association in which species of the classes *Festucetea indigestae* (22.9%) and *Cytisetea* (21.5%) dominate, followed at a distance by the classes *Stipo giganteae–Agrostietea castellanae* (12.5%) and *Tuberarietea* (12.5%).

Synchorology: This association is found in the provinces of Salamanca and Ávila, at 1300–1450 m a.s.l. Béjar and Gredos Sierras Sector (Tormantos Sierran and Béjar Sierran Districts).

Bioclimatology: Lower and middle Supramediterranean bioclimatic belt, under a lower–upper subhumid ombrotype and a pronounced euoceanic level of continentality.

Discussion

This study, which covers the entire range of *E. ibericum*, presents communities that are well defined by their generally endemic, exclusive diagnostic species, while others lack such exclusive diagnostic species in the mountain systems they inhabit. However, the latter are well defined by a particular composition of shared diagnostic species. Currently, vegetation classification is based on so-called exclusive diagnostic species (Barkman, 1989; Chytrý, 2002), but by focusing on these alone, some communities are overlooked. In these cases, the question arises whether only exclusive diagnostic species should be used as the sole criterion for defining vegetation communities, or whether other criteria such as structure/physiognomy and ecology (Ewald, 2003; Willner, 2006; Chiarucci, 2007), as well as cover and distribution, should be taken into account. In this study, an integrative view was used to categorise the different plant communities, distinguishing those with a shared set of diagnostic species and a characteristic distribution range. As can be seen in Figure 1, there are groups of relevés that follow each other altitudinally and in a W–E direction in the NW and C mountains of the Iberian Peninsula. Rivas-Martínez et al. (2001) proposed a classification into two different phytosociological classes: those located at higher altitudes are included in the class *Junipero-Pinetes* and those at basal and middle altitudes in the class *Cytisetea scopario-striati*. Subsequently, and after the description of new syntaxa, different authors carried out studies on the classification of these communities (Costa et al., 2003; Gavilán et al., 2011; Rivas-Martínez et al., 2011; Amor & Ávila, 2012) in which the division into two classes was maintained, although there were discrepancies in the number of accepted syntaxa.

Our analyses identify nine syntaxa with three new variants, which, albeit with some discrepancies, are largely congruent with the described associations but less consistent with their syntaxonomic placement. The greatest controversy surrounds the Supratemperate–Supramediterranean communities of the NW Iberian Peninsula, which have been grouped according to a synthetic criterion in a single association (*Echinopartetum iberici*) (Rivas-Martínez, 2001; Costa et al., 2003; Gavilán et al., 2011; Amor & Ávila, 2012) or treated by maintaining the associations *Festuco summilusitanae*–*Echinopartetum iberici* and *Genisto hystricis*–*Echinopartetum iberici* as syntaxa independent of the former (Rivas-Martínez, 2011). Our results support the independence of the three associations. The bioclimatic parameters of the areas of occurrence differ significantly from one area to another, as reflected in the species present in each area, which include diagnostic species and constant species. Although *Festuco summilusitanae*–*Echinopartetum iberici* lacks exclusive differential species, it exhibits shared diagnostic taxa and a constant floristic composition that clearly distinguishes it from the other two associations (including *Festuca yvesii* subsp. *summilusitana* and *Sedum brevifolium*). *Genisto hystricis*–*Echinopartetum iberici* is characterised by diagnostic and constant species such as *Genista hystrix* and *Leucanthemopsis pulverulenta*, whereas *Echinopartetum iberici* is defined by *Cytisus multiflorus* and *Halimium lasianthum* subsp. *alyssoides*. Our results also confirm the status of *Armerio ciliatae*–*Echinopartetum iberici* as an independent association, which has not previously been included in any review.

For the *Echinopartetum iberici* association, we propose two new high-altitude variants. The typical association (cluster 5) consists of the *Echinopartum* thickets with *Cytisus multiflorus* located below 1320 m a.s.l. It brings together the relevés that occupy the most basal position and present the greatest similarity with the *typus* relevé of the association. Cluster 6 groups the communities located in the adjacent higher altitudinal band (var. with *Halimium lasianthum* subsp. *alyssoides*), which, to date, has only been sampled in the Sierra de Gata. Both variants share the diagnostic species *Cytisus multiflorus* and *Helictochloa marginata*. At higher altitudes and in western Eurosiberian areas (Serra da Estrela *sensu lato*), these communities incorporate *Erica arborea*, while *Cytisus multiflorus* disappears, in response to a decrease in *It* and an increase in *Io*; we recognise these communities as the var. with *Erica arborea* (cluster 4).

We also propose a northern high-altitude variant for *Genisto hystricis*–*Echinopartetum iberici*. The typical association (cluster 2), located at very low altitude within the *E. ibericum* communities, is rich in elements of the class *Cytisetea* (*Cytisus scoparius*, *Genista florida*); with increasing altitude these species are partly replaced by species of the class *Calluno-Ulicetea* (*Pteropartum tridentatum*). This pattern may reflect, at least in part, variation in *Io* and *It*—with increasing *Io* and decreasing *It* along the altitudinal gradient—although other, unmeasured environmental or historical factors may also contribute. The presence of endemic taxa of the class *Festucetea indigestae* contributes to the characterisation of these communities, which we recognise as the var. with *Dianthus laricifolius* subsp. *merinoi* (cluster 3).

Another discrepancy with respect to previous analyses is the grouping of cluster 7 (*Cytisus oromediterranei*–*Echinopartetum pulviniformis*) with cluster 13, which groups together the relevés located altitudinally below them (*Genisto cinerascens*–*Cytisetum oromediterranei* var. with *Echinopartum pulviniforme* *sensu* Sardinero, 2004) and those located in the highest areas of the Sierra de Gata with a northern aspect. This grouping is due to the loss, in the relevés of cluster 13, of the large group of constant and diagnostic species exclusive to the association *Genisto cinerascens*–*Cytisetum oromediterranei* var. with *E. ibericum* (cluster 12) (Table 2). As confirmed by other authors (Amor & Ávila, 2012), in our analysis the relevés of *Echinopartum iberici*–*Juniperetum lagunae* (Cano et al., 2007) are clearly integrated with those of *Genisto cinerascens*–*Adenocarpum argyrophylli* subass. *echinopartetosum iberici* (cluster 11). The remaining associations *Genisto sanabrensis*–*Juniperetum alpinae* subass. *echinopartetosum iberici* (cluster 9) and *Teucro salviastri*–*Echinopartetum pulviniformis* (cluster 8) remain independent syntaxa as in previous ordinations.

The analysis of syntaxa membership in phytosociological classes, according to the flora participating in each association, does not fully fit into traditional syntaxonomy. The inclusion of the associations of the sub-Mediterranean Orotemperate belt in the class *Junipero-Pinetea* is doubtful based on the presence of the participating flora. *Genisto sanabrensis*–*Juniperetum*

alpinae subass. *echinospartetosum iberici* is the only one with a majority cover of species of this class, which also have a notable influence on the associations *Cytiso oromediterranei*–*Echinospartetum pulviniformis* (11.7%, cluster 7), *Teucrio salviastris*–*Echinospartetum pulviniformis* (20%, cluster 8) and *Armerio ciliatae*–*Echinospartetum iberici* (13%, cluster 10). In the first two clusters (clusters 7 and 8), species of the *Cytisetea* dominate, while in *Armerio ciliatae*–*Echinospartetum iberici* species of the class *Festucetea indigestae* dominate (24.7%), although almost to the same extent as the *Cytisetea* species (22.1%). Although in all three cases there is a clear influence of *Junipero-Pinetea* species, in none of them do they have a majority presence, and the linkage of these communities with the syntaxa of the classes *Cytisetea* and *Festucetea indigestae* remains to be studied. Without the influence of *Junipero-Pinetea* species, in the ass. *Genisto cinerascens*–*Cytisetum oromediterranei* var. with *E. ibericum* (cluster 12), species of the class *Festucetea* also dominate (22.9%), although almost to the same extent as the *Cytisetea* species (21.5%). Finally, in *Festuco summilusitanae*–*Echinospartetum iberici* (cluster 1), the dominance belongs to the species of the class *Calluno-Ulicetea*, with *Helictochloa marginata* and *Pterospartum tridentatum* as constant species and the frequent presence of *Erica umbellata*, which leaves open the possibility of placing this association within the *Ericion umbellatae* alliance of the class *Calluno-Ulicetea*.

Conclusions

Although *Echinospartum* gorse scrubs are species-poor owing to their development in extensive rocky montane environments, changes in their characteristic floristic composition were observed, thereby allowing the identification of 13 groups linked to 9 associations. All groups had exclusive and/or shared diagnostic species, together with constant species that characterised each syntaxon. The succession of syntaxa along the west–east (W–E) and altitudinal gradients responded to the climatic variables analysed and was consistent with the biogeographical pattern.

The floristic composition of the communities does not support the inclusion of some syntaxa in the classes *Cytisetea* and *Junipero-Pinetea*. In communities located in the Supramediterranean belt, species of the class *Cytisetea* predominate. With increasing altitude into the sub-Mediterranean Orotemperate belt, the communities become richer in species characteristic of the class *Junipero-Pinetea*, although these are statistically dominant only in ass. *Genisto sanabrensis*–*Juniperetum alpinae* subass. *echinospartetosum iberici*. Communities further north and west incorporate the highest proportion of *Calluno-Ulicetea* species, which are dominant in *Festuco summilusitanae*–*Echinospartetum iberici*, whereas those in the southern half of the Iberian Peninsula are richest in species of the class *Cisto-Lavanduletea*. An increase in *Calluno-Ulicetea* species is also observed in continental mountains with rising altitude. In all groups, acidic rock environments facilitate the establishment of small chamaephytes and hemicryptophytes of the classes *Stipo giganteae*–*Agrostietea castellanae* and *Festucetea indigestae*, indicating their close dynamic relationship with the vegetation analysed.

The syntaxa recognised in this study are summarised in the following syntaxonomic scheme, following Mucina et al. (2016):

CYTISETEA SCOPARIO-STRIATI Rivas-Mart. 1974

Cytisetalia scopario-striati Rivas-Mart. 1974

Genistion floridae Rivas-Mart. 1974

Cytiso oromediterranei–*Genistetum cinerascens* Rivas-Mart. 1970, corr. Rivas-Mart. & Cantó 1987

Variant with *Echinospartum ibericum* Sardinero 2004

Genisto cinerascens–*Adenocarpum argyrophylli* Vicente-Orellana & Galán 2008

subass. *echinospartetosum iberici* Vicente-Orellana & Galán 2008

Cytision multiflori Rivas-Mart. 1974

Festuco summilusitanae–*Echinospartetum iberici* Costa Ten., Morla & Sáinz 1993, corr. Pulgar & Herrera*¹

Genisto hystricis–*Echinospartetum iberici* F. Navarro & C. Valle 1983, corr. Rivas-Mart. 2011 (Typica)

Variant with *Dianthus laricifolius* subsp. *merinoi*
Echinopartetum iberici Rivas-Mart. 1974 corr. Rivas-Mart. & Sánchez-Mata 2002
(Typica)
Variant with *Erica arborea*
Variant with *Halimium lasianthum* subsp. *alyssoides*
Armerio ciliatae-Echinopartetum iberici González de Paz 2012*²

JUNIPERO-PINETEA SYLVESTRIS Rivas-Mart. 1965 Nom. Invers. Propos
Juniperetalia hemisphaericae Rivas-Mart. et J.A. Molina in Rivas-Mart. et al. 1999
Cytisium oromediterranei Tx. in Tx. et Oberd. 1958, corr. Rivas-Mart. 1987
Genisto sanabrensis-Juniperetum alpinae F. Prieto 1983, corr. Rivas-Mart. 2011
subass. *echinopartetosum iberici* Penas et al. 1990
Cytiso oromediterranei-Echinopartetum pulviniformis Rivas-Mart. et al. 1987*³
Teucrio salviastri-Echinopartetum pulviniformis Rivas-Mart. 1974 corr. 1981*³

*Cataloguing of dominant species per association by phytosociological class: (1) *Calluno-Ulicetea*; (2) *Festucetea indigestae*; (3) *Cytisetea*.

Authorship

I.P.:
J.M.H.

Conflict of interest

None.

References

- Amor, A. & Ávila, C. 2012. Endemic communities of *Echinopartum ibericum* Rivas-Martínez, Sánchez-Mata and Sancho and *Echinopartum barnadesii* (Graells) Rothm. in south-western Europe (Iberian Peninsula): a statistical analysis. *Acta Bot. Gallica* 159(2): 149–160. doi: 10.1080/12538078.2012.696929
- Aparicio, A., Albadalejo, R.G. & Ceballos, G.L. 2002. Genetic differentiation in silicicolous *Echinopartum* (Leguminosae) indicated by allozyme variability. *Plant Syst. Evol.* 230: 189–201.
- Borcard, D., Gillet, F. & Legendre, P. 2011. Unconstrained ordination. In: *Numerical Ecology with R*. Pp. 115–151. Springer, Switzerland. doi: 10.1007/s006060200004
- Borcard, D., Gillet, F. & Legendre, P. 2018. *Numerical ecology with R*. 2nd ed. Springer, Switzerland. doi: 10.1007/978-3-319-71404-2
- Braun-Blanquet, J. 1979. *Fitosociología. Bases para el estudio de las comunidades vegetales*. Blume, Madrid.
- Cano, E., Rodríguez-Torres, A., Pinto-Gomes, C., García-Fuentes, A., Torres, J.A., Salazar, C., Ruiz-Valenzuela, L., Cano-Ortiz, A. & Montilla, R.J. 2007. Analysis of the *Juniperus oxycedrus* L. communities in the centre and south of the Iberian Peninsula (Spain and Portugal). *Acta Bot. Gallica* 154(1): 79–99. doi: 10.1080/12538078.2007.10516046
- Castroviejo, S. & al. (Eds.). 1986–2021. *Flora Iberica*. Real Jardín Botánico-CSIC, Madrid.
- Costa, J.C., Aguiar, C., Capelo, J., Lousa, M., Castro, J.H.S., Honrado, J., Izco, J. & Ladero, M. 2003. A classe *Cytisetea scopario-striati* em Portugal Continental. *Quercetea* 4: 45–70.
- Costa Tenorio, M., Morla, C. & Sanz-Ollero, H. 1993. Datos sobre los caméfitos espinosos en los macizos meridionales galaicos. *Lazaroa* 13: 139–147.
- De Caceres, M., Legendre, P. & Moretti, M. 2010. Improving indicator species analysis by combining groups of sites. *Oikos* 119(10): 1674. doi: 10.1111/j.1600-0706.2010.18334.x
- De Caceres, M. & Jansen, F. 2016. Package ‘indicspecies’: Relationship between species and groups of sites. R, ver. 1.7-6. Available from: cran.r-project.org/web/packages/indicspecies/ [Accessed 20 June 2022].

- Dufrêne, M. & Legendre, P. 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. *Ecol. Monogr.* 67(3): 345–366.
- Fick, S.E. & Hijmans, R.J. 2017. WorldClim 2: New 1-km spatial resolution climate surfaces for global land areas. *Int. J. Climatol.* 37(12): 4302–4315. doi: 10.1002/joc.5086
- Gavilán, R.G., Vilches, B. & Fernández-González, F. 2011. Sintaxonomical review of *Cytisetea scopario-striati* communities in central Spain. *Lazaroa* 32: 29–72. doi: 10.5209/rev_LAZA.2011.v32.37252
- González de Paz, L., Ríos, D., del Río, S., Herrero, L. & Penas, A. 2009. La vegetación camefítica templado submediterránea del distrito Berciano (sector Berciano-Sanabrense). XXII Jornadas Internacionales de Fitosociología, Alicante (España).
- Honrado, J.P. 2003. Flora e vegetação do Parque Nacional da Peneda-Gerês. Tesis doctoral inédita, Univ. do Porto.
- Kerguelen, M. & Morla, C. 1985. *Festuca graniticola* nueva especie del noroeste de la península Ibérica. *An. Jard. Bot. Madr.* 42(1): 155–158.
- Legendre, P. & Legendre, L. 2003. Numerical ecology. 3rd ed. Elsevier, Amsterdam.
- Martínez Sagarra, G. & Devesa, J.A. 2021. Sobre el nombre *Festuca yvesii* subsp. *graniticola* (Kerguelen & Morla) Mart.-Sagarra & Devesa. *Acta Bot. Malacit.* 46: 11. doi: 10.24310/abm.v46i0
- Mucina, L. & al. 2016. Vegetation of Europe: hierarchical floristic classification system of vascular plant, bryophyte, lichen, and algal communities. *Appl. Veg. Sci.* 19(1): 3–264. doi: 10.1111/avsc.12257
- Navarro, F. & Valle, C. 1983. Fitocenosis fruticosas de las comarcas zamoranas de Tábara, Alba y Aliste. *Stud. Bot.* 2: 69–121.
- Navarro, F., Sánchez-Anta, M.A., González-Zapatero, M.A., Gallego, F., Elena, J.A. & Valle, C. 1987. Piornales y retamales meso y supramediterráneos salmantinos y zamoranos. *Lazaroa* 7: 337–349.
- Oksanen, J., Blanchet, F.G., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., Minchin, P.R., O'Hara, R.B., Simpson, G.L., Solymos, P., Stevens, M.H.H., Szoecs, E. & Wagner, H. 2018. Package 'vegan': Community Ecology Package. R, ver. 2.5-2. Available from: cran.r-project.org/web/packages/vegan/ [Accessed 20 June 2022].
- Ortiz, S. 1986. Series de vegetación y su zonación altitudinal en el macizo de Pena Trevinca y Serra do Eixo. Tesis doctoral inédita, Univ. de Santiago de Compostela.
- Penas, A. & Díaz González, T.E. 1985. Datos sobre la Alianza *Corynephoru-Plantaginion radicatae* Rivas Goday & Rivas-Martínez 1963 nom. invers. Rivas-Martínez 1975 en el Sector Orensano-Sanabriense. *Acta Bot. Malacit.* 10: 155–166.
- Penas, A., Díaz González, T.E., Díaz González, M., Herrero, L. & Puente, E. 1988. Aportaciones al conocimiento de los piornales (*Cytisetea scopario-striati*) en la provincia de León. In: Homenaje a Pedro Montserrat. Pp. 687–694. Instituto de Estudios Altoaragoneses–Instituto Pirenaico de Ecología.
- Penas, A., Puente, E., Herrero, L., Pérez-Morales, C. & Llamas, F. 1990. La clase Pino-Juniperetea en la provincia de León. *Acta Bot. Malacit.* 15: 217–230.
- R Core Team. 2018. RStudio: Integrated Development for R. RStudio, Inc., Boston, MA. Available from: rstudio.com/ [Accessed 20 June 2022].
- Rivas-Martínez, S. 1974. Datos sobre la flora y la vegetación de la Serra da Estrela (Portugal). *An. R. Acad. Farm.* 40(1): 65–74.
- Rivas-Martínez, S. 1981. Sobre la vegetación de la Serra da Estrela (Portugal). *An. R. Acad. Farm.* 47: 435–480.
- Rivas-Martínez, S., Belmonte, D., Cantó, P., Fernández-González, F., Fuente, V., Moreno, J.M., Sánchez-Mata, D. & Sancho, L. 1987. Piornales, enebrales y pinares oromediterráneos (*Pino-Cytision oromediterranei*) en el Sistema Central. *Lazaroa* 7: 93–124.
- Rivas-Martínez, S., Fernández-González, F., Loidi, J., Lousa, M. & Penas, A. 2001. Sintaxonomical check-list of vascular plant communities of Spain and Portugal to association level. *Itin. Geobot.* 14: 5–341.
- Rivas-Martínez, S. & al. 2011. Mapa de series, geoserias y geopermaseries de vegetación de España. *Itin. Geobot.* 18(1-2): 5–800.

- Rivas-Martínez, S., Penas, A., Díaz-González, T.E., Cantó, P., del Río, S., Costa, J.C., Herrero, L. & Molero, J. 2017a. Biogeographic units of the Iberian Peninsula & Balearic Islands to district level. A concise synopsis. In: Loidi, J. (Ed.). The vegetation of Iberian Peninsula I. Pp. 131–188. Plant and Vegetation 12. Springer, Switzerland. doi: 10.1007/978-3-319-54784-8_5
- Rivas-Martínez, S., Penas, A., del Río, S., Díaz-González, T.E. & Rivas-Sáez, S. 2017b. Bioclimatology of the Iberian Peninsula and the Balearic Islands. In: Loidi, J. (Ed.). The vegetation of the Iberian Peninsula I. Pp. 29–80. Springer, Switzerland. doi: 10.1007/978-3-319-54784-8_2
- Rousseeuw, P.J. 1987. Silhouettes: A graphical aid to the interpretation and validation of cluster analysis. J. Comput. Appl. Math. 20: 53–65.
- Sardinero, S. 2004. Flora y vegetación del Macizo Occidental de la Sierra de Gredos (Sistema Central, España). Guineana 10: 15–436. doi: 10.1387/guineana.5662
- Talavera, S. 1999. *Echinospartum* (Spach) Fourr. In: Castroviejo, S. & al. (Eds.). Flora Iberica 7. Pp. 119–127. Real Jardín Botánico-CSIC, Madrid.
- Valdés Franci, A. 1984. Vegetación arbustiva de la vertiente sur de la Sierra de Gata (Cáceres). Stud. Bot. 3: 179–215.
- Van der Maarel, E. 1979. Transformation of cover-abundance values in phytosociology and its effects on community similarity. Vegetatio 39: 97–114.
- Vicente-Orellana, J.A. & Galán de Mera, A. 2008. Nuevas aportaciones al conocimiento de la vegetación Luso-Extremadurensis. Estudio de las sierras de Las Villuercas (Extremadura, España) y San Mamede (Altoalentejo, Portugal). Acta Bot. Malacit. 33: 169–214. doi: 10.24310/abm.v33i0.6977
- Ward, J.H., Jr. 1963. Hierarchical grouping to optimize an objective function. J. Am. Stat. Assoc. 58: 236–244.

Supplementary material

Figure S1. Pairwise correlation plots for all combinations of bioclimatic indices.

Table S1. Syntaxa, authors, and origin of analysed relevés.

Figures and tables

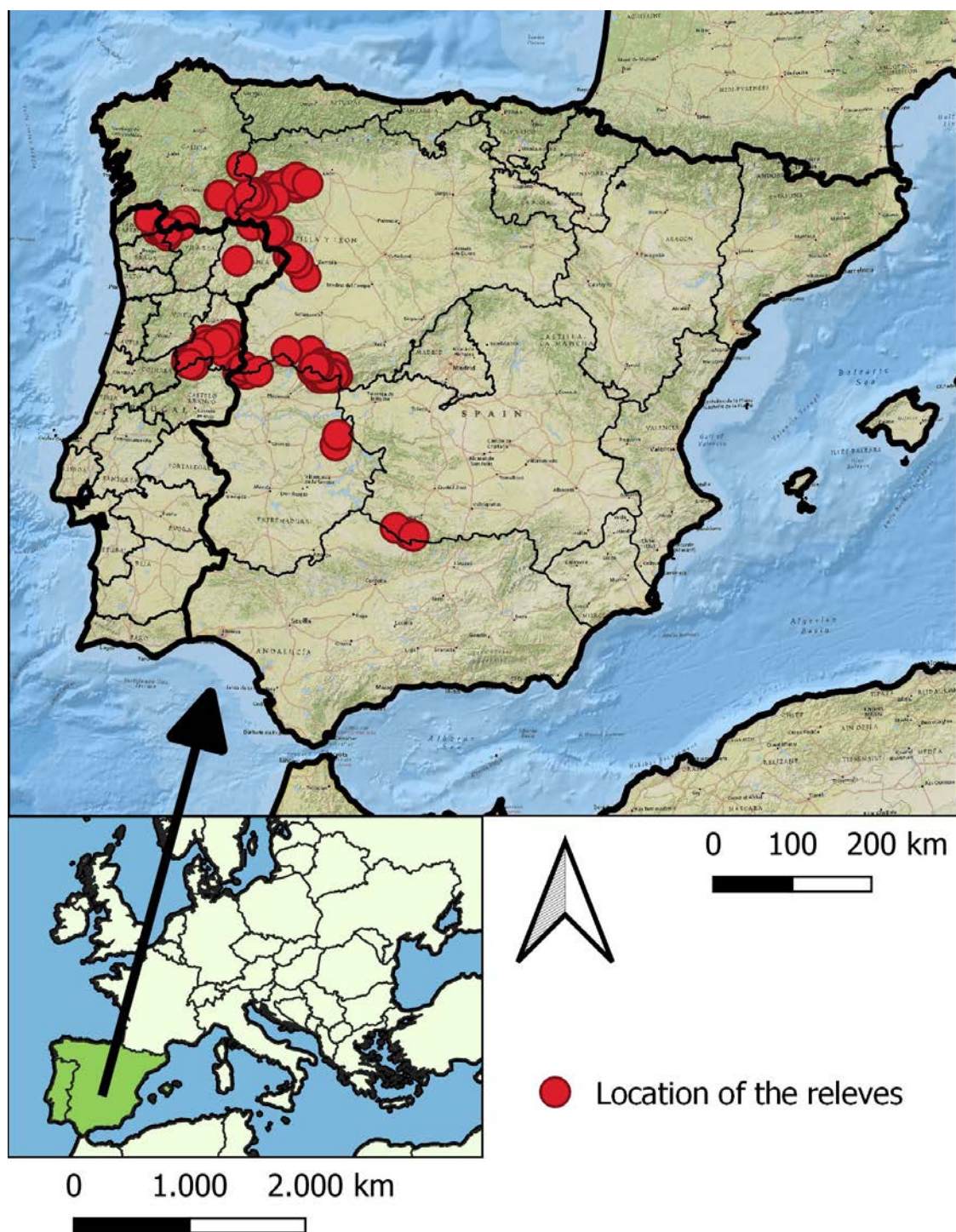


Figure 1. Distribution map of the *Echinopartum ibericum* relevés analysed.

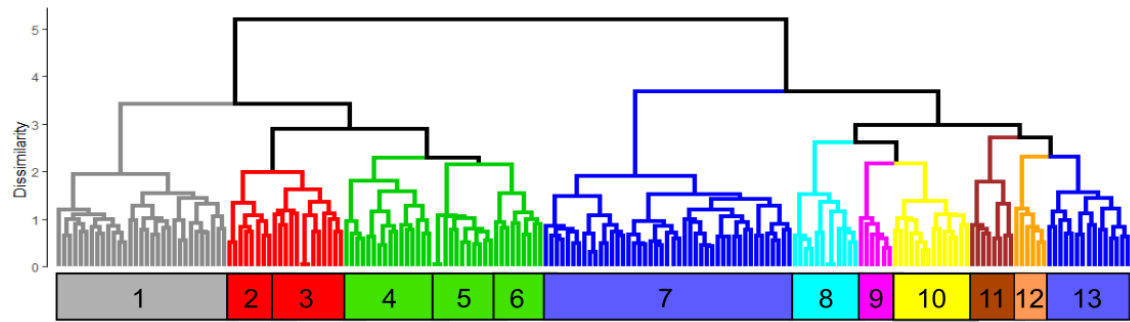


Figure 2. Hierarchical clustering (Hellinger distance and Ward's minimum-variance method) of *Echinopartum* communities. The colours denote the different associations, and the numbers indicate the clusters ($k = 13$). Grey: (1)-*Festuco summilusitanae*-*Echinopartetum iberici*. Red: (2)-*Genisto hystricis*-*Echinopartetum iberici* and (3)-*Genisto hystricis*-*Echinopartetum iberici* var. *Dianthus laricifolius* subsp. *merinoi*. Green: (4)-*Echinopartetum iberici* var. *Erica arborea*, (5)-*Echinopartetum iberici* and (6)-*Echinopartetum iberici* var. *Halimium lasianthum* subsp. *alyssoides*. Dark blue: (7)-*Cytiso oromediterranei*-*Echinopartetum pulviniformis* and (13)-*Cytiso oromediterranei*-*Echinopartetum pulviniformis* (transitional unit). Light blue: (8)-*Teucrio salviastri*-*Echinopartetum iberici*. Pink: (9)-*Genisto sanabrensis*-*Juniperetum alpinae* subass. *echinopartetosum iberici*. Yellow: (10)-*Armerio ciliatae*-*Echinopartetum iberici*. Brown: (11)-*Genisto cinerascens*-*Adenocarpum argyrophylli* subass. *echinopartetosum iberici*. Orange: (12)-*Cytiso oromediterranei*-*Genistetum cinerascens* var. *Echinopartum ibericum*.

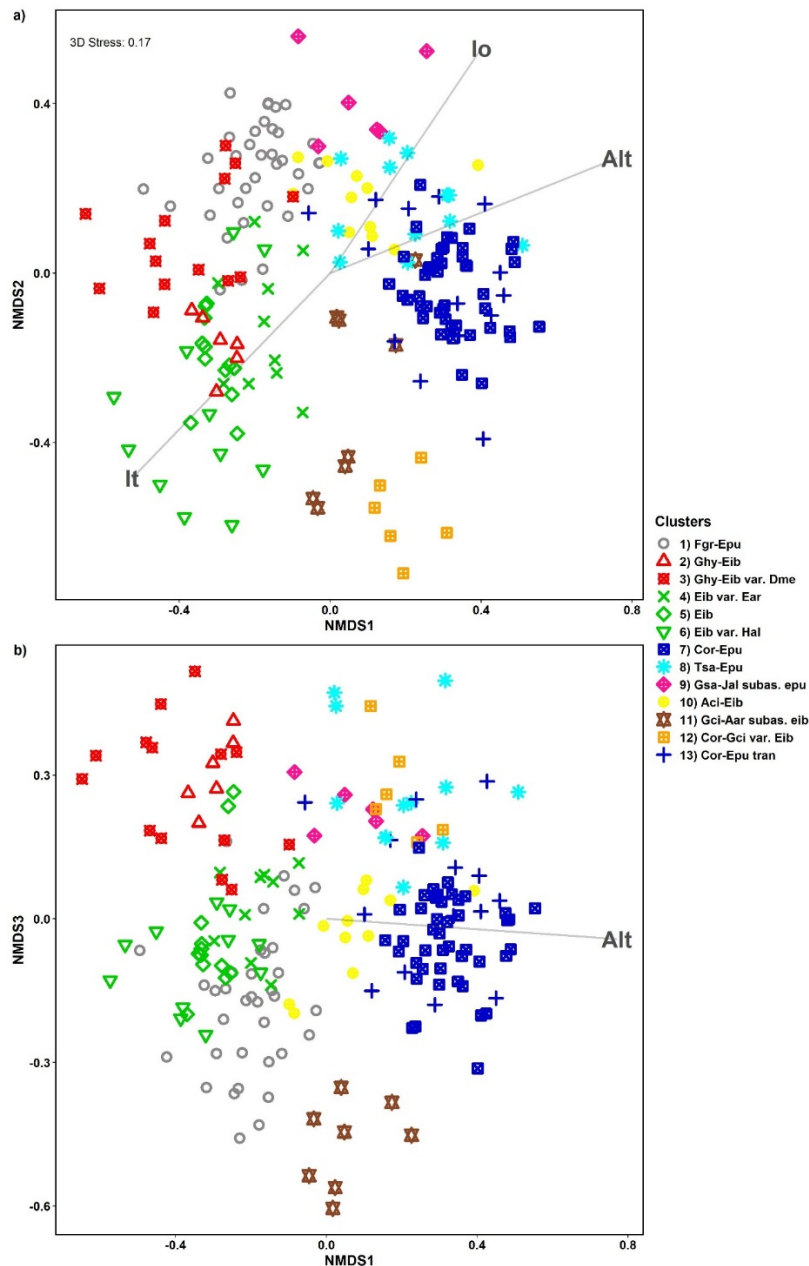


Figure 3. Non-metric multidimensional scaling (NMDS; Hellinger distance). (a) axes 1 and 2; (b) axes 2 and 3. Grey lines denote vectors of environmental variables. Bioclimatic indices: It = thermicity index; Io = ombrothermic index; Ic = continentality index; Alt = elevation. Syntaxon:

Fsu-Eib = *Festuco summilusitanae-Echinopartetum iberici*; Ghy-Eib = *Genisto hystricis-Echinopartetum iberici*; Ghy-Eib var. Dme = *Genisto hystricis-Echinopartetum iberici* var. *Dianthus merinoi*; Eib var. Ear = *Echinopartetum iberici* var. *Erica arborea*; Eib = *Echinopartetum iberici*; Eib var. Hal = *Echinopartetum iberici* var. *Halimium alyssoides*; Cor-Epu = *Cytiso oromediterranei-Echinopartetum pulviniformis*; Tsa-Epu = *Teucro salviastris-Echinopartetum pulviniformis*; Gsa-Jal subas. epu = *Genisto sanabrensis-Juniperetum alpinae* subas. *echinopartetosum iberici*; Aci-Eib = *Armerio ciliatae-Echinopartetum iberici*; Gci-Aar subas. eib = *Genisto cinerascens-Adenocarpum argyrophylli* subas. *echinopartetosum iberici*; Cor-Gci var. Eib = *Cytiso oromediterranei-Genistetum cinerascens* var. *Echinopartetum ibericum*; Cor-Epu tran = *Cytiso oromediterranei-Echinopartetum pulviniformis* (transitional unit).

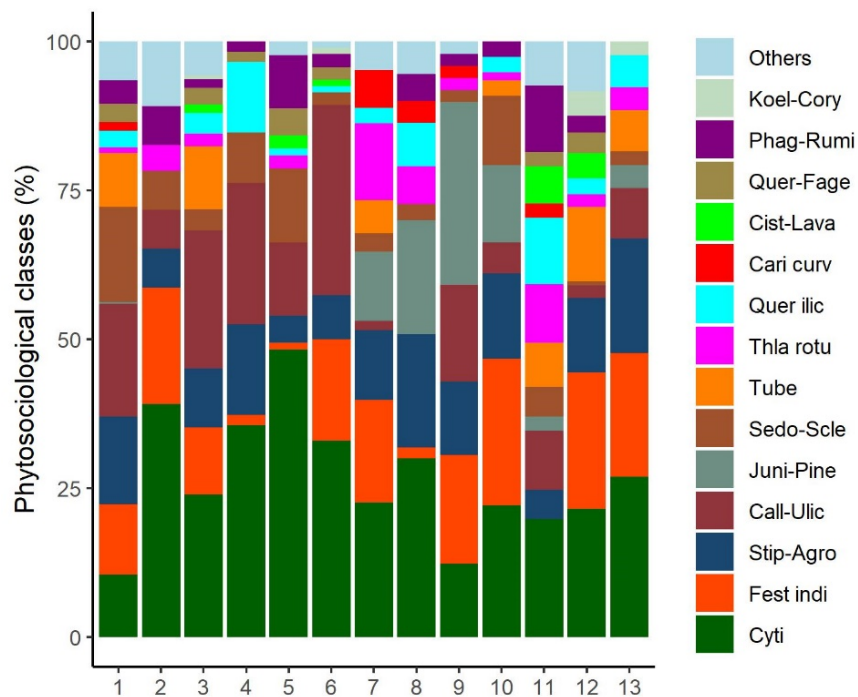


Figure 4. Percentage of phytosociological classes in each of the 13 clusters. Values are weighted by species frequency within clusters. Phytosociological classes: Koel-Cory = *Koelerio-Corynephorsetea canescentis*; Phag-Rumi = *Phagnalo-Rumicetea*; Quer-Fage = *Querco-Fagetetea sylvaticae*; Cist-Lava = *Cisto-Lavanduletea*; Cari curv = *Caricetea curvulae*; Quer ilic = *Quercetea ilicis*; Thla rotu = *Thlaspietea rotundifolii*; Tube = *Tuberarietea*; Sedo-Scle = *Sedo-Scleranthetea*; Juni-Pine = *Junipero-Pinetea*; Call-Ulic = *Calluno-Ulicetea*; Stip-Agro = *Stipogiganteae-Agrostietea castellanae*; Fest indi = *Festucetea indigestae*; Cyti = *Cytisetea*.

Table 1. New relevés (New-Rel) contributing to *Echinospartum ibericum* communities.

Relevé	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Surface (m ²)	10	8	5	10	6	50	6	10	60	10	14	2	8	10	90	20	20
Altitude (x10) (m)	120	102	143	132	132	127	96	123	107	151	153	153	154	153	117	135	102
Cover (%)	40	20	30	30	50	30	60	60	60	40	40	60	30	30	50	30	30
Orientation	S	E	-	SE	-	W	SE	S	E	S	S-SE	SE	S	SE	S-SW	S-SE	S
Incline (%)	5	<5	-	<5	-	<5	5	5	20	<5	5	<5	5	45	5	<5	5
Number of species	13	15	10	9	9	10	10	13	17	9	11	3	8	11	19	8	14
<i>Echinospartum ibericum</i>	2	3	3	3	3	3	2	3	4	2	3	3	3	2	3	2	3
<i>Sedum brevifolium</i>	1	+	2	1	2	2	2	2	3	3	2	.	2	1	1	1	1
<i>Festuca yvesii</i> subsp. <i>summilusitana</i>	2	1	3	3	2	.	2	3	3	2	2	2	3	2	.	1	.
<i>Pterospartum tridentatum</i>	2	1	.	.	+	.	+	.	.	+	2	2	1	1	1	1	1
<i>Neoschischkinia truncatula</i> subsp. <i>duriei</i>	+	1	1	1	1	1	1	.	.	1	.	.	2	.	2	1	.
<i>Thymus caespitosus</i>	.	1	2	1	.	2	.	2	.	+	1	.	1	r	.	1	.
<i>Helictochloa marginata</i>	.	1	1	.	1	.	.	1	r	+	1	.	.	1	+	.	1
<i>Ornithogalum concinnum</i>	+	+	+	.	r	+	1	+	r	.	.	.	.	.	1	.	.
<i>Silene acutifolia</i>	1	.	.	1	+	.	.	r	1	.	.	.	.	.	.	.	.
<i>Erica umbellata</i>	.	+	.	.	.	.	.	+	+	.	.	.	.	.	.	1	1
<i>Minuartia recurva</i>	.	.	.	.	.	.	.	r	.	2	+	.	+	1	.	.	.
<i>Hypochaeris radicata</i>	+	.	.	+	.	.	.	.	.	.	.	.	.	.	.	r	+
<i>Dianthus langeanus</i>	1	.	.	.	.	.	2	.	2	.	.	.	.	.	1	.	.
<i>Logfia minima</i>	.	+	.	.	.	r	.	.	r	.	.	.	.	.	.	.	1
<i>Micropyrum tenellum</i>	.	+	.	.	.	.	1	.	1	.	.	.	.	.	r	.	.
<i>Jasione sessiliflora</i>	r	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	2
<i>Phalacrocarpum oppositifolium</i> subsp. <i>hoffmannseggii</i>	1	.	.	.	.	.	.	.	1	.	.	.	.	.	+	.	.
<i>Sedum hirsutum</i>	1	.	.	.	.	.	.	.	1	.	.	.	.	.	+	.	.
<i>Solidago virgaurea</i>	.	.	.	1	.	.	.	.	.	r	.	.	.	.	.	.	1
<i>Armeria humilis</i> subsp. <i>humilis</i>	.	.	.	.	+	.	.	.	.	.	r	.	1	.	.	.	.
<i>Holcus gayanus</i>	.	.	.	.	.	.	.	.	1	.	.	.	.	r	1	.	.
<i>Spergula morisonii</i>	.	.	.	.	.	.	.	.	.	.	r	.	.	r	r	.	.
<i>Erica arborea</i>	+	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.
<i>Narcissus bulbocodium</i>	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Agrostis curtisii</i>	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
<i>Calluna vulgaris</i>	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
<i>Rumex angiocarpus</i>	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	+
<i>Molineriella laevis</i>	.	.	.	.	.	+	+	.	.	.	.	.	.	.	.	.	.
<i>Halimium umbellatum</i> subsp. <i>umbellatum</i>	.	.	.	.	.	2	.	.	2	.	.	.	.	.	.	.	.
<i>Conopodium majus</i>	.	.	.	.	.	.	.	1	1	.	.	.	.	.	.	.	.
<i>Allium sphaerocephalon</i>	.	.	.	.	.	.	.	r	+	.	.	.	.	.	.	.	.

Species in a single relevé: **Nº 2:** *Scilla monophylla* (+). **Nº 3:** *Allium ericetorum* (r) and *Hyacinth*

Table 2. Synoptic table of species constancy (%) by cluster. Taxa with constancy < 20% in all clusters are excluded. Values in parentheses indicate mean cover; * denotes dominant species; bold denotes diagnostic species (IndVal ≥ 0.4 ; $p \leq 0.01$); dark grey shading indicates constancy $\geq 50\%$ (including 50%); light grey shading indicates constancy $\geq 20\%$ and < 50%.

Clusters	1	2	3	4	5	6	7	8	9	10	11	12	13
Syntaxon	Fsu-Eib	Ghy-Eib	Ghy-Eib var. Dme	Eib var. Ear	Eib	Eib var. Hal	Cor-Epu	Tsa-Epu	Gsa-Jal suba s. epu	Ac-Eib	Gci-Aar suba s. eib	Cor-Gci var. Eib	Cor-Epu (tran)
Number of relevés	36	6	15	10	13	11	45	13	6	11	8	6	14
<i>Echinopartum ibericum</i> (mean cover)	(35) *	(58) *	(31)*	(60) *	(55) *	23	(54) *	(31) *	19	(60) *	15	(36) *	(32) *
Genisto hystricis-Echinopartum iberici (Typical)													
<i>Genista hystrix</i>	0	100	93	0	15	0	0	0	0	0	0	0	0
<i>Leucanthemopsis pulverulenta</i>	0	67	0	0	8	0	0	0	0	0	0	17	0
Genisto hystricis-Echinopartum iberici var. Dianthus laricifolius subsp. merinói													
<i>Dianthus laricifolius</i> subsp. merinói	0	0	40	0	0	0	0	0	0	0	0	0	0
Echinopartum iberici var. Erica arborea													
<i>Erica arborea</i>	25	0	27	70	8	9	22	62	0	18	13	0	50
Echinopartum iberici (Typical)													
<i>Cytisus multiflorus</i>	11	0	0	10	100	100	0	0	0	0	0	0	0
Echinopartum iberici var. Halimium lasianthum subsp. alyssoides													
<i>Halimium lasianthum</i> subsp. alyssoides	17	17	7	60	8	91	0	0	0	0	0	0	14
Teucrio salviastrae-Echinopartum pulviniformis													
<i>Phalacrocarpum oppositifolium</i> subsp. oppositifolium	6	0	0	0	0	0	0	100	0	0	0	0	0
<i>Teucrium saliastrum</i>	0	0	0	0	0	0	0	77	0	0	0	0	0
Genisto sanabrensis-Juniperetum alpinae subas. echinopartetosum iberici													
<i>Genista sanabrensis</i>	0	0	0	0	0	0	0	0	100	18	0	0	0
Armerio ciliatae-Echinopartum iberici													
<i>Armeria ciliata</i>	0	0	0	0	0	0	0	0	0	100	0	0	0
Genisto cinerascens-Adenocarpum argyrophylli subas. echinopartetosum													
<i>Adenocarpus argyrophyllus</i>	0	0	0	0	0	9	0	0	0	0	75	0	0
<i>Dianthus lusitanicus</i>	0	0	0	0	0	9	0	38	0	0	100	0	0
<i>Halimium ocymoides</i>	0	0	0	0	0	0	0	0	0	0	50	0	0
<i>Quercus rotundifolia</i>	3	0	7	0	0	0	0	0	0	0	50	0	0
Cytiso oromediterranei-Genistetum cinerascens var. Echinopartum ibericum													
<i>Euphorbia oxyphylla</i>	0	0	0	0	0	0	0	0	0	0	0	83	0
<i>Thymus zygis</i>	0	0	7	0	0	0	0	0	0	0	0	83	0
<i>Corynephorus canescens</i>	0	0	7	0	0	9	0	0	0	0	0	100	21
<i>Lavandula pedunculata</i>	0	0	7	0	15	0	0	0	0	0	38	100	0
<i>Cytisus scoparius</i>	0	50	20	0	15	9	0	0	0	0	0	100	0
<i>Adenocarpus complicatus</i>	0	0	0	0	0	0	0	0	0	0	0	67	7
<i>Armeria trasmontana</i>	3	0	0	0	0	0	0	0	0	9	0	67	7
<i>Centaurea alba</i>	0	0	0	0	0	0	0	0	0	0	0	50	0
<i>Genista tournefortii</i>	0	0	0	0	0	0	0	0	0	0	0	50	0
<i>Quercus pyrenaica</i>	6	0	7	10	15	0	0	0	0	0	25	83	0
<i>Festuca elegans</i>	14	0	7	20	0	0	0	8	0	0	25	83	43
Other species													
<i>Ornithogalum concinnum</i>	44	67	0	10	0	0	0	0	0	0	0	0	0
<i>Pteridium aquilinum</i>	0	0	0	40	0	18	0	0	0	0	0	67	0
<i>Genista cinerascens</i>	0	0	0	0	54	0	0	31	0	0	25	83	29
<i>Juniperus communis</i> subsp. alpina	0	0	0	0	0	0	2	92	100 (42) *	18	0	0	0
<i>Sedum brevifolium</i>	83	0	13	20	0	9	27	23	0	55	50	0	21
<i>Digitalis thapsi</i>	0	33	0	0	62	9	0	0	0	0	0	67	0
<i>Arenaria quereioides</i>	3	0	0	0	0	64	7	0	0	0	0	83	50
<i>Arrhenatherum elatius</i>	0	0	0	0	0	0	47	8	0	0	75	0	29
<i>Neoschischkinia truncatula</i> subsp. truncatula	0	0	0	0	0	18	73	8	0	0	0	67	71
<i>Pterospartum tridentatum</i>	50	0	53	0	8	27	0	0	67	9	0	0	0
<i>Neoschischkinia truncatula</i> subsp. durieui	61	50	20	30	85	9	0	0	0	27	0	0	0

<i>Helictochloa marginata</i>	61	0	67	70	46	55	7	0	17	0	0	0	7
<i>Festuca yvesii</i> subsp. <i>summilusitana</i>	81	0	27	20	0	18	49	46	100	100	0	0	79
<i>Avenella flexuosa</i>	3	0	0	0	0	0	100	69	50	55	25	0	36
<i>Cytisus oromediterraneus</i>	0	0	0	10	0	0	89	38	0	45	0	100	93
<i>Juniperus oxycedrus</i> subsp. <i>badia</i> (<i>lagunae</i>)	0	0	0	0	0	0	0	0	0	0	50	17	0
<i>Allium paniculatum</i>	0	0	0	0	0	0	0	0	0	0	0	33	0
<i>Festuca lambinonii</i>	0	0	0	0	0	0	0	0	0	0	0	33	0
<i>Helianthemum apenninum</i>	0	0	0	0	0	0	0	0	0	0	0	33	0
<i>Leucanthemopsis boissieri</i>	0	0	0	0	0	0	33	0	0	0	0	0	0
<i>Santolina rosmarinifolia</i>	0	33	0	0	0	0	0	0	0	0	0	33	0
<i>Agrostis castellana</i>	0	0	33	0	0	27	0	0	0	0	0	67	21
<i>Dianthus langeanus</i>	36	0	0	0	0	0	0	0	17	27	0	0	0
<i>Reseda gredensis</i>	0	0	0	0	0	0	31	0	0	0	0	0	0
<i>Rumex angiocarpus</i>	25	0	7	10	0	0	53	0	0	0	0	17	14
<i>Jasione sessiliflora</i>	19	17	0	0	0	9	24	8	0	0	0	67	7
<i>Narcissus asturiensis</i>	0	0	0	0	0	0	0	31	0	0	0	0	0
<i>Stipa gigantea</i>	0	50	0	40	31	9	0	0	0	0	0	17	14
<i>Filago carpetana</i>	0	0	7	0	0	0	0	0	0	0	0	33	0
<i>Genista florida</i>	0	50	0	30	0	18	0	0	0	0	0	0	14
<i>Thymus caespitius</i>	28	0	0	0	0	0	0	0	0	0	0	0	0
<i>Umbilicus rupestris</i>	0	33	7	0	0	0	0	0	0	0	0	0	0
<i>Jasione montana</i>	0	0	13	0	0	0	0	0	0	0	38	0	0
<i>Viola langeana</i>	0	0	0	0	0	27	0	0	0	0	0	0	0
<i>Armeria caballeroi</i>	0	0	27	0	0	0	0	0	0	0	0	0	0
<i>Logfia minima</i>	25	0	7	0	0	0	2	0	0	0	0	50	7
<i>Halimium umbellatum</i> subsp. <i>viscosum</i>	3	33	20	0	15	9	0	0	0	0	0	50	0
<i>Cistus ladanifer</i>	0	0	0	0	0	0	0	0	0	0	25	0	0
<i>Conopodium subcarneum</i>	0	0	0	0	0	0	0	0	0	0	25	0	0
<i>Jasione crispa</i> subsp. <i>tomentosa</i>	0	0	0	0	0	0	0	0	0	0	25	0	0
<i>Cytisus striatus</i>	0	0	0	20	38	27	0	0	0	0	0	0	7
<i>Leucanthemopsis pallida</i>	0	0	0	0	0	0	4	0	0	0	0	33	21
<i>Silene foetida</i>	0	0	0	0	0	0	0	23	0	0	0	0	0
<i>Erica umbellata</i>	25	0	13	0	0	27	0	0	0	0	0	0	0
<i>Erica australis</i>	11	0	0	10	0	27	0	0	17	18	25	0	36
<i>Pilosella castellana</i>	0	0	0	0	0	9	0	0	0	0	0	33	7
<i>Aira carryophyllea</i>	0	0	20	0	0	0	0	0	0	0	0	0	0
<i>Erica cinerea</i>	0	0	20	0	0	0	0	0	0	0	0	0	0
<i>Minuartia recurva</i>	17	0	0	0	0	0	2	31	0	0	0	0	0
<i>Arnoseris minima</i>	6	0	7	0	0	0	4	0	0	0	0	33	14
<i>Teesdalia nudicaulis</i>	0	0	7	0	0	0	7	0	0	9	0	33	7
<i>Sedum hirsutum</i>	25	17	7	0	0	0	0	0	0	9	0	0	0
<i>Microphyrum tenellum</i>	22	0	13	0	0	0	4	0	0	0	38	0	7
<i>Cerastium ramossissimum</i>	0	0	0	0	0	0	16	0	0	0	0	33	7
<i>Jurinea humilis</i>	0	0	0	0	0	0	20	0	33	9	0	0	7
<i>Linaria saxatilis</i>	3	33	13	0	15	0	7	0	0	0	25	0	0
<i>Luzula lactea</i>	3	0	0	0	0	18	7	0	0	0	0	0	21
<i>Plantago holosteum</i>	6	0	20	0	0	0	0	0	0	9	0	17	0
<i>Ranunculus nigrecens</i>	8	0	20	0	0	0	0	0	0	0	0	0	0
<i>Calluna vulgaris</i>	6	0	20	0	0	9	0	0	17	9	13	0	0
<i>Koeleria crassipes</i>	3	0	13	0	0	9	9	0	0	0	0	17	21
<i>Festuca paniculata</i> s.l.	11	0	0	0	0	9	0	0	0	0	25	0	7