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The cartography of vegetation in the cryoromediterranean belt of Sierra Nevada: a tool for biodiversity conservation

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Abstract: Fernández Calzado, M.R. & Molero Mesa, J. *The cartography of vegetation in the cryoromediterranean belt of Sierra Nevada: a tool for biodiversity conservation. Lazaroa 32: 101-115 (2011).*

Geographic Information Systems are tools which have been used with great interest in vegetation studies. The mapping process developed to store data about vegetation and flora in the upper vegetation belt of Sierra Nevada (South-Eastern Spain) is shown. The aim was to elaborate a detailed cartography that served into future to detect changes in plant communities. The extension of the crioromediterranean belt was estimated in 3875.7 ha, ranging between 2750-3290 m of altitude. We have detected thirteen endemic plant communities and four variants inside, all of them are commonly distributed with low cover and very disperse form. The total of quantified taxa was 185, with more than 37 % of them are endemic of the Baetic range. Our study suggests that the Geographic Information systems are good tools for the study of very complex territories as high mountain areas. They generated information that could be used as a testimony to observe the current climatic change processes.

Keywords: high mountain, plant communities, boundaries, climatic change, Sierra Nevada.

Resumen: Fernández Calzado, M.R. & Molero Mesa, J. *La cartografía de la vegetación en el piso crioromediterráneo: una herramienta para la conservación de la biodiversidad. Lazaroa 32: 101-115 (2011).*

Los Sistemas de Información Geográfica son herramientas que son muy utilizadas en estudios de vegetación. En este trabajo se ha realizado una cartografía detallada de la vegetación y la flora que habitan del piso crioromediterráneo de Sierra Nevada que podría servir para detectar cambios en las comunidades vegetales si fuera necesario. Se ha estimado que el piso crioromediterráneo de Sierra Nevada ocupa 3875,7 Ha entre 2750 m y 3290 de altitud. Se han detectado trece comunidades endémicas y cuatro variantes dentro de las mismas, todas ellas distribuidas de forma muy dispersa y baja cobertura. Se han cuantificado 185 taxones con más de un 37% endémico de la provincia Bética. Nuestro estudio sugiere que los Sistema de Información Geográfica son buenas herramientas para estudiar complejos territorios como son las altas montañas, pues son capaces de generar información de gran utilidad para la observación de procesos de cambio climático.

Palabras clave: alta montaña, comunidades vegetales, límites, cambio climático, Sierra Nevada.

INTRODUCTION

Several authors have emphasized that one of the best places to observe the actual processes of climatic change are the highest areas of the mountains (DULLINGER & *al*., 2007; GRABHERR & *al*., 1994; KÖRNER, 1994; PAULI & *al*., 1996; THEURILLAT, 1995). It is due to the fact that, among other reasons, these regions show steep ecological gradients, narrow ecotones and comprise real wilderness habitats with ecosystems which are less disturbed by direct anthropogenic influence (PAULI & *al*., 2004).

Already at the end of the XIX century and the beginning of the XX, these upper mountain areas caught the attention of many researchers (EMBERGER, 1936; OZENDA, 1975; QUÉZEL, 1979; RIVAS-MARTÍNEZ, 1981; MARTÍNEZ-PARRAS & *al*., 1987; CANTÓ & RIVAS-MARTÍNEZ, 2002). Nowadays, these vegetation fringes are denominated vegetation belts (with various names depending on the region, i.e. subalpine and alpine vegetation belts in Alps, oro

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and cryoromediterranean belts in Mediterranean region (Rivas-Martínez & *al*., 2007) and their areas and boundaries are zones where many studies on migrations or upward shifts of flora and vegetation are focused.

In relation to this, there is some evidence of the increase of alpine species richness and upwards migrations in the Alps (Bahn & Körner, 2003; Grabherr & *al*., 2001; Hofer, 1992; Pauli & *al*., 1996, 2001) and Scandinavia (Klanderub & Birks, 2003).These observations indicate that alpine vegetation and the distribution limits of its species do respond to climate change despite the long-lived and slow-growing nature of alpine plants. It also confirms that the highest zones and transition areas (ecotones) of mountains play an important role in the awareness of the climate change because they are critical zones where possible changes might be easily detected.

Nowadays, with the help of Geographic Information systems (GIS) we could obtain an integral view of the vegetation, contributing to the already existing information thanks to the available digital cartography (digital elevation models, radiation, geology, etc). These tools integrate significant amount of data and enable access to different information analyses useful to conservation, management and assessment of factors in relation to populations, vegetation or ecosystems.

Referring to biodiversity conservation, GIS tools play an important role in the studies related to the current climatic change processes facilitating the development of species or communities' spatial distribution models, helping in threat assessment under different scenarios, etc.

In the context of biodiversity, the Mediterranean basin has been recognized as one of most important diversity centres (Médail & Quézel, 1997, 1999) where the South of Spain (Andalusia) stands out. This is where the Sierra Nevada massif is situated characterised by a great floristic biodiversity, high endemicity rate and numerous threatened taxa (Morales & *al*., 1986; Suárez-Cervera & Sedane-Camba, 1986; Pardo, 1982; Rivas-Martinez & Saénz-Laín, 1985; Blanca & Molero Mesa, 1990; Blanca & *al*., 1998; Molero Mesa, 1987, 1996; Myers, 2000; Quézel, 1953; Rivas Goday & Mayor López, 1966; Rivas-Martínez & *al*., 1991). Several studies have indicated the vulnerability and sensitivity of this mountain to the climatic change effects (Fernández González & *al*., 2005; Grabherr & *al*., 2000), which has resulted in the increase of national and international conservation projects. Among them, the Global Observation Research Initiative in Alpine Environments (GLORIA) which works in alpine environments over the world, maintaining a long term observation network at different levels (vascular plants, temperatures, lichens, etc).

With the intention of complementing the GLORIA monitoring work in Sierra Nevada, over the last years we have developed a study of vegetation to detailed scale (1:10 000) in the highest zone of this massif (cryoromediterranean belt). We have obtained a wider and a more global view of the situation of this vulnerable territory and, at the same time, detailed data about its altitudinal boundaries, flora and vegetation. This data has been integrated in the GIS where the user can perform easy queries, analyses and superimpose layers of different information. We believe that in the future this information will be used as historical record and serve as point of departure for the study of the vegetation change trends.

METHODS

Study area

The study area is located on the South Eastern Iberian Peninsula (Figure 1), where the maximum Iberian Peninsula altitudes are reached (Mulhacen, 3481 m), and distributed by the eastern zone of Baetic range with an extension of 3875.7 ha (Fernández Calzado, 2007). This territory is included in one biogeographic unit although it is actually heterogeneous enough. All the area is protected inside a National Park with a high number of sites proposed in the Habitat Directive (Anonymous, 1992). Considering the entire massif, we can observe the striking diversity of different environments where the diverse vegetation types are distributed along the environmental gradients such as altitude, soils or humidity. In the upper zone, the conditions become more severe

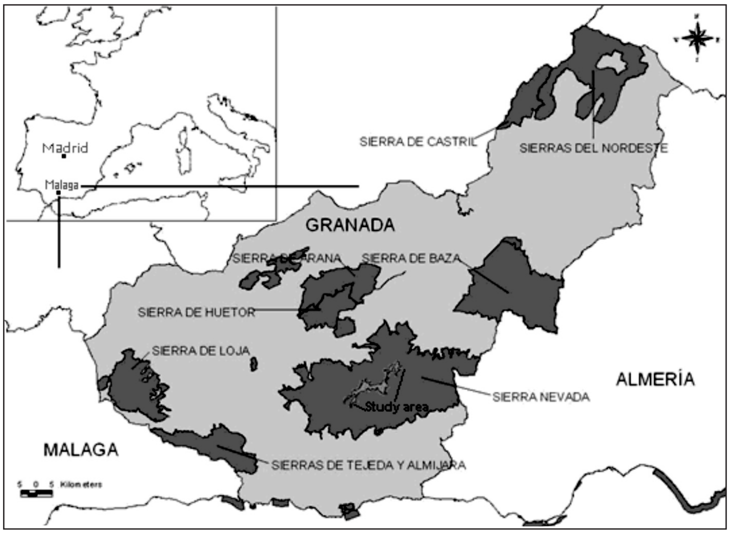

Figure 1. – Location of the study area.

and the vegetation is exposed to stressful climate conditions with large daily temperature oscillations and a pronounced summer drought.

This is the reason why, the study area represents a unique place in Europe as far as the use of vegetation mapping to contribute useful data for conservation policies, assessment and management of the different vegetation types faced with the effects of climatic change.

It is necessary to clarify that in the current paper we only comment on the data collected on the upper vegetation belt of Sierra Nevada although the real study surface was extended to a larger area (35274.56 ha) with the intention to guarantee an exhaustive and complete inclusion of the whole territory and its boundaries.

Digital mapping process

Before the altitudinal delimitation, we performed a mapping process to store information about the flora and vegetation of the study area. This information, over all the distribution of climatophilous plant associations (Fernández Calzado & Molero Mesa, 2010), and the use of other analysis tools, would allow us to later obtain our final goal: the delimitation of upper vegetation belt of Sierra Nevada.

The first step of the mapping process was a photointerpretation of the vegetation territory using black and white digital orthophotographies (scale 1:20 000) from Andalusia government (Junta de Andalucía). The process was done with the GIS ArcView 3.3 for Windows (Environmental Systems Research Institute Inc, CA).

On the orthophotographies the units or polygons were delimitated using as differentiator character, the range of tonalities and textures that appear on the photo. Of this form, the different units that we have separated foresee differences also with regard to the communities that they present.

During the field work phase we collected quantitative and qualitative data about the flora, physiognomic and vegetation structure to support the photointerpretation of the vegetation units. This information was taken on a high number of sample localities inside our study territory; exactly they were 289 phytosociologial relevées following the phytosociological method (Braun-Blanquet, 1979) and more than 400 single notes. All the information generated was stored in Access database and later digitalised in independent units to facilitate the queries.

Once finished the mapping process we modified the available information including different data such as predictive distribution species models or temperature maps, which were very useful to complement the existing information about our territory (Fernández Calzado, 2007).

RESULTS AND DISCUSSION

VEGETATION DATA ANALYSIS

Following, we will make a contribution with some data that highlight the originality and ecological diversity of the upper vegetation belt of Sierra Nevada (cryoromediterranean belt). The analysis of these vegetation data gives us an idea of the territory richness on community level (EL AALLALI, 2003; LOSA QUINTANA, & *al*., 1986; MARTÍNEZ PARRAS & *al*., 1987; MOLERO MESA, 1984; PRIETO, 1971; QUÉZEL, 1953; RIVAS GODAY & MAYOR, 1966; RIVAS-MARTÍNEZ 1969; PÉREZ RAYA & *al*., 1990; RIVAS-MARTÍNEZ & *al*., 1986; RIVAS-MARTÍNEZ & *al*., 2001, 2002). In this environment, the climatic, microtopographic and edaphic situations, which are so changeable, have originated this great number of ecological spaces in vicinity populated by vivacious permanent vegetation communities in a fragile balance. In this context, the detailed cartography has been very useful, helping us to know and assess with more accuracy the vegetation of Sierra Nevada upper belt.

This vegetation belt has an extension of 3875.7 ha with its low-found boundaries ranging between 2750 m in the northern and western zones, and 3290 m in the southern and oriental zones. Both altitudes are joined by means of an irregular line (FERNÁNDEZ CALZADO, 2007). Add, in spite of its reduced extension, the territory is heterogeneous with a total of 317 units or polygons (Figure 2).

The quantitative and qualitative data show the behaviour of this massif as an island, since it appears isolated from the rest of neighbouring territories and with less human impact constituting an adequate space for the study of the biodiversity. If we look at the plant associations (100%) and taxa (30%) endemism rates in the upper vegetation belt, they increase from lower altitude confirming our island pattern.

On this upper vegetation belt, the most common situation is that the plant communities occupy the territory with low cover and in dispersed form probably due to the hard ecological conditions which make their establishment difficult. In the majority of cartographic units the space is shared by several associations; therefore units with only one dominant association are rare. This is the

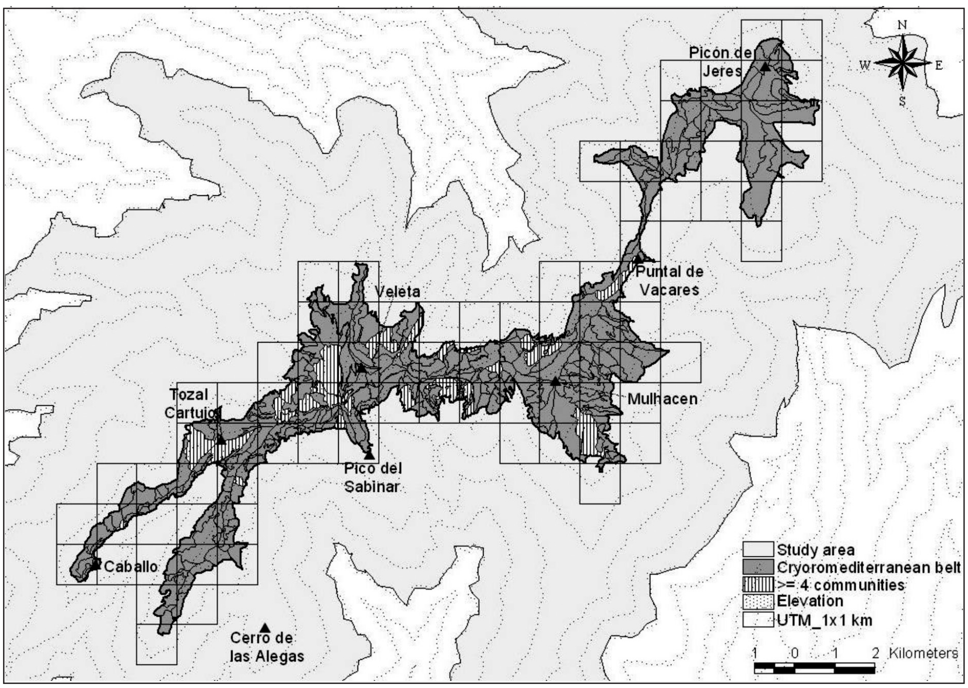

Figure 2. – General vision of the study area and cryoromediterranean belt (Elevation lines each 250 m).

reason why the sum of their areas and the number of units where they are represented is bigger than the real one on the territory (superimposed areas).

We have distinguished the presence of thirteen endemic plant associations and four variants (Annexe 1: syntaxonomical scheme). Among them are especially relevant the psicroxerophitic grasses of *Festuca clementei* (*Erigeronto frigidi-Festucetum clementei, Festucetea indigestae*), the cliff vegetation (*Saxifragetum nevadensis, Asplenietea trichomanis*) and the scree community (*Violo crassiusculae-Linarietum glacialis, Thlaspietea rotundifolii*). These plant communities represent the most common vegetation in the upper zone alternating with different communities which shift upwards from the low vegetation belt, especially in the ecotone (*Campanulo willkommii-Polystichetum lonchitidis, Thlaspietea rotundifolii; Festucetum moleroio-pseudoeskiae* and *Cirsio gregarii-Dactyletum juncinellae, Festucetea indigestae*), and other from humid environments in this vegetation belt and in the lower one as well (*Sedo melanantheri-Saxifragetum alpigenae, Montio-Cardaminetea; Veronico turbicolae-Festucetum rivularis* and *Ranunculo acetosellifolii-Vaccinietum nani, Scheuchzerio-Caricetea nigrae*; etc).

If we analyses in detail the information about the most important plant communities on this territory we could understand better their roles in the cryoromediterranean belt. For example, the most representative permanent association of cryoromediterranean geopermasigmetum is *Erigeronto frigidi-Festucetum clementei,* distributed on very discontinuous form, from 2800-2900 m up to the higher summits, since in the area that potentially occupies predominate rocky and stony areas (2608.82 ha, 28.51%, Table 1). This community is extremely rich in endemism such as *Festuca clementei, Erigeron frigidus, Trisetum glaciale, Artemisia granatensis* or *Galium pyrenaicum*, which supports an intense drought, changing between three and five months, according to the year.

After the study of the available inventories from the bibliography and the realized ones in this investigation, we distinguish the presence of four variants in the association (Table 1). These are influenced by the different ecological conditions such as the *Vaccinium uliginosum* subsp. *nanum* variant, located in depression and shady slopes where the snow has a prolonged persistence; the *Hormathophylla spinosa* variant which marks the transition to stony zones being enriched with species such as *Sempervivum minutum* o *Biscutella glacialis*; etc. Therefore, the four variants are interesting because have a significant value in the landscape and are composed by chamaephytes. This type of life form probably represents a recent colonization from lower vegetation belt except for the *Vaccinium nanum* variant which is postglacial taxa in regression (FERNÁNDEZ CALZADO & MOLERO MESA, 2010). The differentiation at this level could serve as another control point adding to the whole vegetation belt monitoring area.

Violo crassiusculae-Linarietum glacialis has scarce coverture alternating with the psicroxerophitic grasses on scree zones, although with a minor surface (1982 ha, 21.66%, Table 1). It does not mean less interest because the elevated percentage of endemism such as *Linaria glacialis, Viola crassiuscula, Chaenorrhinum glareosum* or *Coincya monensis* subsp. *nevadensis* is undoubtedly.

The last community, more common on the upper belt, is *Saxifragetum nevadensis* (1133.82 ha, 12.39%, Table 1), which is located on vertical cliffs, inside cracks or protected cavities. Its flora is adapted to resist the enormous thermic oscillations with characteristic species as *Saxifraga nevadensis, Saxifraga oppositifolia, Draba dubia, Murbenkiella bory* or *Asplenium viride*.

These three communities alternate, most of all in the ecotone, with *Campanulo willkommii-Polystichetum lonchitidis, Festucetum moleroio-pseudoeskiae* and *Cirsio gregarii-Dactyletum juncinellae*, more typical in the lower vegetation belt. The first one has a great representation (973.79 ha, 10.64%, Table 1), but it is not a striking phenomenon. Although it can live in the lower belt, the common cliffs in the cryoromediterranean belt make its establishment possible, sharing the area with associations such as *Saxifragetum nevadensis*. Their species, a lot of them being pteridophytes (*Polystichum lonchitis, Criptogramma crispa, Dryopteris filix-mas, Polystichum aculeatum*), live in the holes of the blocks, ecology related with the Quaternary glaciation centred between Trevélez's Hills (eastern), and

Table 1
Extracted data of the alpine vegetation communities
(Abbreviations: N, Number of polygons; N shared, Number of shared polygons; A, Area(ha); %, Percentage of associations; Freq., Frequency of vegetation community as first)

Vegetation communities	N	N shared	A	%	Freq.
Armerio splendentis-Agrostietum nevadensis	9	9	49.26	0.54	1
Campanulo willkommii-Polystichetum lonchitidis	90	89	973.79	10.64	9
Cirsio gregarii-Dactyletum juncinellae	23	23	342.9	3.75	6
Festucetum baetico-pseudoeskia	53	50	786.43	8.6	14
Erigeronto frigidi-Festucetum clementei	180	156	2608.82	28.52	138
Erigeronto frigidi-Festucetum clementei var. Arenaria pungens	6	6	163.56	1.79	3
Erigeronto frigidi-Festucetum clementei var. Hormathophylla spinosa	16	16	254.96	2.79	12
Erigeronto frigidi-Festucetum clementei var. Sideritis glacialis	5	3	54.21	0.59	5
Erigeronto frigidi-Festucetum clementei var. Vaccinium nanum	13	11	308.18	3.37	8
Veronico turbicolae-Festucetum rivularis	5	5	40.73	0.45	0
Leontodo microcephali-Ranunculetum uniflori	15	15	10.4	0.11	0
Nardo strictae-Festucetum ibericae	31	30	246.9	2.7	13
Omalotheco pusillae-Lepidietum stylati	29	29	502.55	5.49	0
Ranunculo acetosellifolii-Vaccinietum nani	8	8	38.46	0.42	0
Saxifragetum nevadensis	111	108	1133.82	12.39	59
Sedo melanantheri-Saxifragetum alpigenae	9	9	47.66	0.52	0
Violo crassiusculae-Linarietum glacialis	136	129	1982	21.66	46
Festucetum baetico-pseudoeskia	53	50	786.43	8.6	14

Caballo's peak (western). Also the community, more impoverished, can live on wide cracks of cliffs or mobile scree.

The second one, *Festucetum moleroio-pseudoeskiae* (786.43 ha, Table 1), dispersed on the whole of the territory, colonize sunny dry slopes far from water. Its average altitude is 2700 m although *Festuca pseudoeskia* can goes down more enough. Another characteristic species come from *Nevadension* alliance.

Finally, *Cirsio gregarii-Dactyletum juncinellae* (342.9 ha, Table 1) is a pasture characterized by the endemism *Dactylis juncinella*. It grows on poor siliceous soils, often visited by flocks of goats and sheeps.

The rest of plant associations are present in a higher or lower degree depending on the habitats available for them. We want to emphasize that a low community extension does not mean less importance. This is the case of communities which are in relation to the presence of springs or humidity in the substrate, i.e. *Leontodo microcephali-Ranunculetum uniflori, Veronico turbicolae-Festucetum rivularis, Sedo melanantheri-Saxifragetum alpigenae* or *Ranunculo acetosellifolii-Vaccinietum nani*, among others. The suitable conditions for these communities are limited in the highest zone of the massif but their roles stressed because they are exclusive in the world, functioning on many occasions as refuge for taxa from coldest epochs which are on the limit of their distribution areas.

Focusing on the flora, the floristic notes recorded in the field work phase were useful to elaborate a cryoromediterranean catalogue (Annexe 2). It was an important fact since the taxa work as bioindicators and they also helped us to identify the vegetation belt boundaries. The number of recorded taxa was 185 presenting different altitudinal distributions (FERNÁNDEZ CALZADO, 2007): 18 (9.73%) are exclusive of cryoromediterranean belt, among these species there are some with very scanty populations, on the verge of the disappearance i.e. *Draba dubia* subsp. *laevipes* or *Valeriana apula*; 115 (62.16%) can live in the oro and cryoromediterranean conditions, some of them proceeding from the coldest epochs using the territory as a refuge i.e. *Asplenium septentrionale* or *Gentiana alpina*; and 52 (28.11%) could live in more than two vegetation belts, it is essential to emphasize the surprising altitudinal distribution of *Hormatophylla spinosa*, which stretches from mesomediterranean belt up to the highest part of Sierra Nevada being recent the settling on the high summits (BOISSIER, 1839-1845).

From the total number of taxa, 29.73% (55) are restricted and do not exceed the geographical limits of Sierra Nevada such as *Saxifraga nevadensis, Artemisia granatensis* or *Arenaria nevadenis*; 7.57 % (14) are also present, in many cases on nominal form, on any high Andalusian surrounding mountain (*Avenula levis* or *Crepis oporinoides*); and the rest, 116 taxa (62.7%), are distributed over different territories (Iberian Peninsula, Europe, etc). Among the last ones, there are some taxa of special interest because they spread from the Alpine mountains up to Sierra Nevada marking the last territory in the south of Europe where they could be found (*Artemisia umbelliformis* or *Festuca rivularis*).

CONSERVATION

We think that this work is of great interest since it is the first time that an identification of plant communities has been done facilitating fine-scale mapping and providing a tool for better monitoring of biodiversity, management and conservation policies.

Due to the location of study territory inside a National Park, the majority of its plant communities are included in the Habitat Directive (CEE, 1992) and the plant species which compose them are protected by the Spanish legislation. As a consequence the territory will be protected in the future, therefore if any vegetation change occurs it will only be as a result of changes in the environmental conditions.

We have already detected some changes on the upper vegetation belt extension if we compare it with the inexactly ancient estimations. For example, BOISSIER (1839-1845) situated the lower limit of the highest vegetation belt on 2600 m (MOLERO MESA & FERNÁNDEZ CALZADO, 2010) while QUÉZEL (1953) ranged it on 2900 m (without differences between northern and southern slopes). On the other hand, RIVAS-MARTÍNEZ & *al*. (1987) and VALLE & *al*. (2003) gave their extension estimations in accordance with the bioclimatic belt being around 5000 ha. None of these estimations coincide with our information since these days the territory has a smaller surface (3875.7 ha). This reduction means less space for the association and their flora, which will have not space for upwards migrations in the future. Adding, the chamaephytes species such as *Arenaria pungens, Hormathophylla spinosa, Sideritis glacialis*, or even, *Thymus serpylloides*, are today prospering in the area, therefore the chamaephytes and hemicryptophyte mixture observe by QUÉZEL (1953) at 3000 m reach now higher altitudes.

Finally, in relation to the biodiversity, if we divide the upper vegetation belt area with a 1 km^2 UTM squared net it will occupy 86 squares (not all in a complete form, see Figure 2). Thirty one of them, which are situated on upper altitudes and valleys, have a high number of plant communities that goes from four up to eleven, i.e. Veleta square. Therefore the conservation of these squares would suppose the protection of a high floristic diversity, many of them on a threatened and vulnerable situation.

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ANNEXE 1. Syntaxonomical scheme

VEGETATION OF SPRINGS AND BOGS

MONTIO-CARDAMINETEA Br.-Bl. & Tüxen ex Br.-Bl. 1948
Montio-Cardaminetalia Pawlowski in Pawlowski, Sokolowski & Wallisch 1928
Myosotidion stoloniferae Rivas-Martínez, T. E. Díaz, F. Prieto, Loidi & Penas 1984
Sedo melanantheri-Saxifragetum gredensis Martínez Parras, Peinado & Alcaraz
SCHEUCHZERIO-CARICETEA NIGRAE Tüxen 1937
Caricetalia nigrae Koch 1926
Festucion frigidae Rivas- Martínez, Diez-Garretas, Asensi, Molero & F. Valle 2002
Leontodonto microcephali-Ranunculetum alismoidis Esteve & P. Prieto in P. Prieto 1971
Veronico turbicolae-Festucetum rivularis Quezel 1953

CHASMOPHYTIC AND SCREE VEGETATION

ASPLENIETEA TRICHOMANIS (Br.-Bl. in Meier & Br.-Bl. 1934) Oberdofer 1977
Androsacetalia vandellii Br.-Bl. in Meier & Br.-Bl. 1934
Saxifragion nevadensis Litardiére ex Quézel 1953
Centrantho nevadensis-Sedetum brevifolii Quézel 1953
Saxifragetum nevadensis Litardiére ex Quézel 1953
THLASPIETEA ROTUNDIFOLII Br.-Bl. 1948
Androsacetalia alpinae Br.-Bl. in Br.-Bl. & Jenny 1926
Holcion caespitosi Quézel 1953
Violo crassiusculae-Linarietum glacialis Quézel 1953
Polystichetalia lonchitidis Rivas Martínez, T.E. Díaz, F. Prieto, Loidi & Penas 1984
Dryopteridion oreadis Rivas Martínez 1977
Campanulo willkommii-Polystichetum lonchitidis (Esteve & Fernández Casas 1971) Molero 1985

SUPRATIMBERLINE CLIMACTICAL ZONAL VEGETATION ON CRYOPHILOUS GELITURBATED SOILS. CIRCUMARCTIC AND EUROSIBERIAN VEGETATION

SALICETEA HERBACEAE Br.-Bl. 1948
Salicetalia herbaceae Br.-Bl. in Br.-Bl. & Jenny 1926
Sedion candollei Rivas Martinez, Fernández González & Loidi 1999
Omalotheco pusillae-Lepidietum stylati Martinez Parras, Peinado & Alcaraz 1987

WEST-MEDITERRANEAN OROPHILOUS SILICICOLOUS VEGETATION

FESTUCETEA INDIGESTAE Rivas Goday & Rivas Martínez 1971
Festucetalia indigestae Rivas Goday & Rivas Martínez in Rivas Martínez 1963
Nevadension purpureae Quézel 1953
Nevadensienion purpureae Rivas Martínez, Fernández-González & Sánchez-Mata 1986
Erigeronto frigidi-Festucetum clementei Quézel 1953
Erigeronto frigidi-Festucetum clementei var. Sideritis glacialis
Erigeronto frigidi-Festucetum clementei var. Arenaria pungens
Erigeronto frigidi-Festucetum clementei var. Vaccinium nanum
Erigeronto frigidi-Festucetum clementei var. Hormathophylla spinosa
Festucetum moleroio-pseudoeskiae Quézel 1953
Thymenion serpylloidis (Rivas Goday & Rivas Martínez in Rivas Martínez 1964) Rivas Martínez, Fernández González & Sánchez Mata 1986
Cirsio gregarii-Dactyletum juncinellae Molero & López 2002

MEADOW AND CHIONOPHILOUS GRASSLAND VEGETATION

NARDETEA STRICTAE Rivas Goday in Rivas Goday & Rivas Martínez 1963
Nardetalia strictae Oberdorfer ex Preising 1949
Campanulo herminii-Nardenalia Rivas-Martínez, Fernández González & Sánchez Mata 1986
Plantaginion nivalis Quézel 1953
Armerio splendentis-Agrostietum nevadensis Quézel 1953
Nardo strictae-Festucetum ibericae Quézel 1953
Ranunculo acetosellifolii-Vaccinietum nani Quézel 1953

ANNEXE 2. Checklist of cryoromediterranean plant species of Sierra Nevada (185 taxa). For every taxa the following information is accounted: Thermotype, M = mesoditerranean, S = supramediterranean, O = oromediterranean, C = cryoromediterranean; Conservation status, CR = critically endangered, EN = endangered, VU = vulnerable, NL = not list; Distribution, Ne = Nevadensian, Be = Baetican, Ib = Iberian, Ib-N = Iberian-Northern Africa, Eu = European, Eu-N = European-Northern Africa, Others = widely distributed

TAXA	Thermotype	Threaten	Distribution
Acinos alpinus (L.) Moench subsp. *meridionalis* (Nyman) P.W.Ball	S,O,C	NL	Eu-N
Aconitum vulparia Reichenb. Ex Spreng. subsp. *neapolitanum* (Ten.) Muñoz Garmendia	S,O,C	NL	Eu-N
Agrostis canina L. subsp. *granatensis* Romero García, Blanca & C. Morales	O,C	VU	Ne
Agrostis nevadensis Boiss.	O,C	NL	Ne
Alchemilla glabra Neygenf.	S,O,C	NL	Eu
Alchemilla saxatilis Buser	O,C	NL	Eu
Alyssum nevadense Willmmott ex P.W.Ball & R. Dudley	O,C	VU	Ne
Anarrhinum laxiflorum Boiss.	S,O,C	NL	Ib-N
Androsace vandelli (Turra) Chiov.	O,C	NL	Eu
Androsace vitaliana (L.) Lapeyr. subsp. *nevadensis* (Chiarugi) Luceño	O,C	VU	Ne
Antennaria dioica (L.) Gaertner var. *congesta* DC.	C	VU	Others
Anthericum baeticum (Boiss.) Boiss.	S,O,C	NL	Ib-N
Anthyllis vulneraria L. subsp. *pseudoarundana* H.Lindb	O,C	NL	Ne
Arabis alpina L.	S,O,C	NL	Others
Arenaria tetraquetra L. subsp. *amabilis* (Bory) H. Lindb. fil.	O,C	NL	Ne
Arenaria armerina Bory	S,O,C	NL	Ib-N
Arenaria nevadensis Boiss. & Reuter	C	CR	Ne
Arenaria pungens Clemente ex Lag.	O,C	NL	Be
Armeria filicaulis (Boiss.) Boiss. subsp. *nevadensis* Nieto Feliner, Rosselló & Fuertes.	O,C	VU	Ne
Armeria splendens (Lag. & Rodr.) Webb	O,C	VU	Ne
Arrhenaterum elatius (L.) Beauf. subsp. *baeticum* Romero Zarco	S,O,C	NL	Ib-N
Artemisia granatensis Boiss.	O,C	CR	Ne
Artemisia umbelliformis Lam.	C	EN	Eu
Asperula aristata L. fil. subsp. *scabra* (J. & C.Presl.) Nyman	M,S,O,C	NL	Eu-N
Asplenium ruta -muraria L.	S,O,C	NL	Others
Asplenium septentrionale (L.) Hoffm.	O,C	NL	Others
Asplenium viride Hudson	O,C	NL	Others
Astragalus incanus L.	M,S,O,C	NL	Eu-N
Avenella iberica (Rivas Martínez) Rivas Martínez, Fern-Gonz & Loidi.	O,C	NL	Ib
Avenula levis (Hackel) J. Holub	O,C	VU	Be
Biscutella glacialis (Boiss. & Reut.) Jordan	O,C	NL	Ne
Botrychium lunaria (L.) Swartz	O,C	VU	Others

Bunium macuca Boiss. subsp. *nivale* (Boiss.) Mateo & López Udias	O,C	NL	Ne
Campanula herminii Hoffmm. & Link.	O,C	NL	Ib
Campanula rotundifolia L. subsp. *hispanica* (Willk. in Willk. & Lange) O. Bolos & Vigo	O,C	NL	Eu
Cardamine resedifolia L.	O,C	NL	Eu-N
Carduus carlinoides Gouan subsp. *hispanicus* (Kazmi) Franco	O,C	NL	Ne
Carex capillaris L.	O,C	NL	Others
Carex echinata Murray	O,C	NL	Others
Carex furva Webb	O,C	NL	Ib
Carex leporina L.	S,O,C	NL	Others
Carex nevadensis Boiss. & Reuter	O,C	NL	Be
Carex nigra (L.) subsp. *intricata* (Tineo) Rivas Martínez	O,C	NL	Others
Centranthus nevadensis Boiss.	S,O,C	VU	Be
Cerastium alpinum L. subsp. *aquaticum* (Boiss.) Martínez Parra & Molero Mesa	C	NL	Ne
Cerastium alpinum L. subsp. *nevadense* (Pau) Martínez Parra & Molero Mesa	C	NL	Ne
Cerastium cerastoides (L.) Britton	O,C	NL	Others
Cerastium ramosissimum Boiss.	S,O,C	NL	Others
Chaenorrhinum glareosum (Boiss.) Willk	O,C	NL	Ne
Cirsium gregarium Boiss. ex. Willk.	O,C	NL	Be
Coincya monensis (L.) Greuter & Burdet subsp. *nevadensis* (Willk.) Leadlay	O,C	NL	Ne
Comastoma tenellum (Rottb.)Toyok.	O,C	VU	Others
Conopodium bunioides (Boiss.) Calestani	O,C	NL	Ib
Crepis oporinoides Boiss.	O,C	NL	Be
Cryptogramma crispa (L.) R. Br. ex Hooker	O,C	NL	Others
Cuscuta planiflora Ten.	O,C	NL	Others
Cystopteris fragilis (L.) Bernh subsp. *fragilis*	M,S,O,C	NL	Others
Cystopteris fragilis (L.) Bernh subsp. *alpina* (Lam.) Hartman	S,O,C	NL	Eu
Cystopteris fragilis (L.) Bernh subsp. *huteri* (Hausm. ex Milde) Prada & Salvo	C	NL	Eu
Dactylis juncinella Bory	O,C	NL	Ne
Dianthus pungens L. subsp. *brachyanthus* (Boiss.) Bernal, Fern. Casas, G. López, M. Lainz & Muñoz Garm.	S,O,C	NL	Ib-N
Draba dubia Suter subsp. *laevipes* (DC) B- Blanq. In Trav.	C	VU	Eu
Draba hispanica Boiss. subsp. *laderoi* Rivas Martínez, M.E. García & Penas	O,C	NL	Ne
Dryopteris filix-max (L.) Schott	M,S,O,C	NL	Others
Eleocharis quinqueflora (F.X.Hartmann) O.Schwartz	O,C	NL	Others
Epilobium alsinifolium Vill.	O,C	NL	Eu
Epilobium anagallidifolium Lam.	O,C	NL	Others
Epilobium atlanticum Litard. & Maire	S,O,C	VU	Ib-N
Erigeron frigidus Boiss. ex DC	C	VU	Ne
Erigeron major (Boiss.) Viehr	O,C	NL	Be

Erodium cheilanthifolium Boiss.	S,O,C	NL	Be
Eryngium glaciale Boiss	O,C	NL	Ib-N
Euphorbia esula L.	S,O,C	NL	Others
Euphorbia nevadensis Boiss. & Reut.	O,C	NL	Ib
Euphrasia willkommii Freyn	O,C	NL	Ib-N
Festuca clementei Boiss.	C	VU	Ne
Festuca frigida (Hackel) K. Richter	O,C	VU	Ne
Festuca iberica (Hackel) K. Richter	O,C	NL	Ib-N
Festuca indigesta Boiss.	S,O,C	NL	Ib-N
Festuca pseudoeskia Boiss.	O,C	NL	Ne
Festuca rivularis Boiss.	O,C	NL	Eu
Fritillaria lusitanica Wikstr.	M,S,O,C	NL	Ib-N
Gagea nevadensis Boiss.	M,S,O,C	NL	Ib-N
Galium nevadense Boiss. & Reuter	O,C	NL	Ib-N
Galium pyrenaicum Gouan	O,C	NL	Ib
Galium rosellum (Boiss.) Boiss. & Reuter	O,C	NL	Be
Gentiana alpina Vill.	O,C	VU	Eu
Gentiana boryi Boiss.	O,C	VU	Ib
Gentiana pneumonante L. subsp. *depressa* (Boiss.) Malag.	O,C	VU	Ne
Gentiana sierrae Briquet (*Gentiana verna* L.)	O,C	VU	Ne
Helictotrichon filifolium (Lag.) Henrad subsp. *velutinum* (Boiss.) Romero Zarco	S,O,C	NL	Ib-N
Helictotrichon sedenense (Clarion ex DC.) J. Holub	S,O,C	NL	Eu-N
Herniaria boissieri Gay	O,C	NL	Be
Hieracium pilosella L. subsp *melanops* Peter	S,O,C	NL	Eu
Holcus caespitosus Boiss.	O,C	NL	Ne
Hormathophylla spinosa (L.)Kupfer	M,S,O,C	NL	Eu-N
Hypericum undulatum Schousboe ex Willd.	M,S,O,C	NL	Eu-N
Iberis carnosa Wild subsp. *embergeri* (Serve) Moreno	C	EN	Ne
Jasione crispa (Pourr.) Samp. subsp. *tristis* (Bory) G. López	O,C	NL	Ne
Juncus alpinoarticulatus Chaix	O,C	NL	Eu
Juncus tenageia Ehrh. ex L. fil.	O,C	NL	Others
Juniperus communis L. subsp. *hemisphaerica* (K.Presl) Nyman	S,O,C	NL	Others
Leontodon boryi Boiss.	O,C	NL	Be
Leontodon microcephalus (Boiss.) Boiss.	O,C	VU	Ne
Lepidium stylatum Lag.& Rodr.	O,C	NL	Ne
Leucanthemopsis pectinata (L.) G. López & Ch. E. Jarvis.	O,C	NL	Ne
Linaria glacialis Boiss.	C	VU	Ne
Linaria nevadensis (Boiss.) Boiss & Reut.	O,C	NL	Ne
Logfia arvensis (L.) J.Holub	M,S,O,C	NL	Eu
Lotus corniculatus L. subsp. *glacialis* (Boiss.) Valdés	O,C	NL	Ne
Luzula hispanica Chrtek & Krisa	O,C	NL	Ib
Meum athamanticum Jacq.	O,C	NL	Eu-N
Montia fontana L. (N)(S-O-C)	S,O,C	NL	Others
Murbeckiella boryi (Boiss.) Rothm.	O,C	NL	Ib-N
Myosotis minutiflora Boiss. & Reuter	M,S,O,C	NL	Others
Nardus stricta L.	O,C	NL	Eu-N
Nepeta nepetella L. subsp. *laciniata* (Willk.) Aedo.	S,O,C	NL	Ne

Nevadensia purpurea (Lag. & Rodr.) Rivas Martínez	O,C	NL	Ne
Omalotheca supina (L.) DC. var. *pusilla* (Haenke) Amich, Rico & Sánchez	O,C	NL	Eu
Papaver lapeyrousianum Guterm.	C	EN	Ib
Parnassia palustris L.	S,O,C	NL	Others
Paronychia polygonifolia (Vill.) DC	S,O,C	NL	Others
Pedicularis verticillata L. subsp. *caespitosa* (Webb) I. Soriano	C	VU	Ne
Phleum abbreviatum (Boiss.) Rivas Martínez, Asensi, Molero Mesa & Valle	O,C	VU	Ne
Phyteuma charmelii Vill.	O,C	VU	Eu
Pimpinella procumbens (Boiss.) Pau	O,C	VU	Ne
Pinguicula nevadensis (Lindb.) Casper	O,C	VU	Ne
Plantago holosteum Scop.	S,O,C	NL	Eu
Plantago nivalis Boiss.	O,C	NL	Ne
Poa laxa Haenke	O,C	NL	Eu
Poa ligulata Boiss	S,O,C	NL	Ib-N
Poa minor Gaudin subsp. *nevadensis* Nannfeldt	O,C	NL	Ne
Poa nemoralis L. subsp. *glauca* (Gaudin) Rouy	S,O,C	NL	Eu
Poa supina Schrader	S,O,C	NL	Others
Polygonum aviculare L.	O,C	NL	Others
Polystichum lonchitis (L.) Roth	O,C	NL	Others
Potentilla nevadensis Boiss.	O,C	NL	Ne
Ranunculus acetosellifolius Boiss.	O,C	NL	Ne
Ranunculus angustifolius subsp. *alismoides* (Bory) Malagarriga	O,C	NL	Ne
Ranunculus demissus DC	O,C	NL	Others
Ranunculus glacialis L.	C	VU	Eu
Reseda complicata Bory	O,C	NL	Ne
Rhamnus pumila Turra	O,C	NL	Others
Ribes alpinum L.	O,C	VU	Eu-N
Sagina saginoides subsp. *nevadensis*	O,C	NL	Ib
Sagina procumbens L.	*S,O,C*	*NL*	*Others*
Saxifraga granulata L.	M,S,O,C	NL	Others
Saxifraga nevadensis Boiss.	O,C	NL	Ne
Saxifraga oppositifolia L.	C	NL	Others
Saxifraga gredensis Rivas Mateos	O,C	VU	Ib
Scutellaria jabalambrensis Pau	O,C	NL	Ib
Sedum amplexicaule DC	M,S,O,C	NL	Others
Sedum annuum L.	O,C	NL	Eu
Sedum brevifolium DC	O,C	NL	Eu-N
Sedum candollei Raym.-Hamet	O,C	NL	Ib
Sedum dasyphyllum L.	O,C	NL	Eu-N
Sedum melanantherum DC	O,C	NL	Ib-N
Sempervivum minutum (Kunze ex Willk.) Nyman ex Pau	S,O,C	NL	Be
Senecio boissieri DC.	O,C	NL	Ib
Senecio nebrodensis L.	S,O,C	NL	Ib
Senecio nevadensis Boiss. & Reut.	O,C	VU	Ne

Senecio pyrenaicus Loefl. subsp. *granatensis* (Boiss. ex DC) Rivas Martínez	O,C	NL	Be
Sesamoides prostrata (Boiss.) G. López.	S,O,C	NL	Be
Sibbaldia procumbens L.	C	VU	Others
Sideritis glacialis Boiss.	O,C	NL	Ne
Silene boryi Boiss.	S,O,C	NL	Ib
Silene rupestris L.	O,C	NL	Eu
Silene saxifraga L.	S,O,C	NL	Eu
Solidago virgaurea L. subsp. *minuta* (L.) Arcangeli	O,C	NL	Others
Taraxacum nevadense H. Lind. fil.	O,C	NL	Ne
Thymus serpylloides Bory	O,C	NL	Ne
Trifolium pratense L.	M,S,O,C	NL	Others
Trifolium repens L. subsp. *nevadense* (Boiss.) D.E. Coombe	S,O,C	NL	Ib
Trisetum antonii-josephii Font Quer & Muñoz Medina	O,C	EN	Ne
Trisetum glaciale (Bory) Boiss. (*Trisetum glacile* Boiss.)	C	VU	Ne
Vaccinium uliginosum L. subsp. *nanum* (Boiss.) Rivas Martínez, Asensi, Molero Mesa & Valle	O,C	NL	Ne
Valeriana apula Pourret	C	VU	Ib-N
Veronica alpina L.	O,C	NL	Others
Veronica fruticans Jacq	O,C	NL	Others
Veronica nevadensis (Pau) Pau	O,C	NL	Ib
Veronica ponae Gouan	O,C	NL	Ib
Vicia pyrenaica Pourret	S,O,C	NL	Eu
Viola crassiuscula Bory	O,C	NL	Ne
Viola hirta L.	S,O,C	NL	Others
Viola palustris L.	O,C	NL	Others