The bioclimates of Sierra Nevada National Park

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Abstract:

For the first time, the bioclimatic maps of ombrotypes, thermotypes, and “Average monthly temperature below 0ºC”, have been delineate at scale 1:250000 in Sierra Nevada National Park (SNNP), in accord with the “Potential natural vegetation series and geopermaseries” and the last global approach of “Worldwide Bioclimatic Classification System” (RIVAS-MARTINEZ, RIVAS SAENZ & PENAS, 2011). At the same time, we also published the biogeographic map of SNNP, in which on recognize two provinces, five sectors and eight districts: IId. Murcia and Almería Province, 40. Almería Sector: 40c. West Almería District; IIe. Bética Province, 42. Hoyas de Guadix and Baza Sector: 42a. Hoya de Guadix District; 43. Nevada Sierran Sector: 43a. East Nevada Sierran District, 43b. High Nevada Sierran District; 44. Alpujarras and Gádor Sierran Sector: 44a. Gádor Sierran District, 44b. Alpujarras District; 45. Granada and Almijara Sierran Sector: 45a. Vega de Granada District, 45c. Trevenque Sierran District; following the recent “Typological biogeographic synopsis of Spain and Portugal” (RIVAS-MARTINEZ & AL., 2014).

Key Words: Sierra Nevada National Park (Spain), Global Geobotany, Phytosociology, Bioclimatology, Biogeography.

Introduction

Two years ago, a group of professional geobotanists of universities and research centers (P. Cantó, S. Del Río, T.E. Díaz, V.E. Martín, J. Molero, A. Penas, S. Rivas-Martínez & W. Wildpret) in solidarity decided to improve the field work researches on vegetation dynamic and global geobotany in the Spanish National Parks, firstly in which the altitude of the main summits exceed the timber line. The National Parks selected for the initial programme were: Sierra Nevada (responsibles: J. M. Molero & J.M. Marfil), Sierra de Guadarrama (responsibles: S. Rivas-Martínez & P. Cantó) and Picos de Europa (responsibles: A. Penas, T.E. Díaz & S. del Río) in the Iberian Peninsula, and Teide (responsibles: W. Wildpret & V.E. Martin) in Tenerife, Canary Islands. For the second programme (2018-2020): Ordesa-Monte Perdido and Aigües Tortes-San Maurici. The principal aims of the researches are to know better the global geobotanic models and to compare theirs biogeographic territories using bioindicators: flora,vegetation communities, habitats, vegetation series and clinosequences, as well as the significance of the bioclimatic and biogeographic units. We also decided that the responsibilities of any national park project could freely request help or cooperation to any qualified non profitable scientific or thecnic useful expert. And furthermore, the “solidarity group” must be able to offer a high standard and accurate information on botanical and geobotanical topics to the scientific community and to the staff members of the national parks responsible of the management and conservation.

Materials and methods

Notions on bioclimatology and biogeography

Bioclimatology is a geobotanical science that study the reciprocity between the climate and the distribution of living bodies and their communities on Earth. This discipline, that has been also called Phytoclimatology, began to be structured as a result of connecting numeric climate values (much temperature and rainfall data) with the areas of plants, formations, plant communities, ecosystems and biomes, adding at a later stage information of biogeocenosis and knowledges from dynamic -catenal phytosociology (vegetation series, geoseries, permaseries and geopermaseries).

For more than three decades, RIVAS-MARTÍNEZ & AL. (2002, 2011a) has been trying to develop a worldwide bioclimatic classification; the reasons were to dispose an easily quantifiable bioclimatic typology that show a close relationship between the vegetational components and climate values, at the same time, considering the high predictive value of the bioclimatic units, could be used in other sciences, in studies and conservation programmes for biodiversity, as well as in agricultural, forestry resources, and climate change. The increasingly detailed knowledge in the distribution of vegetation on Earth, as well as modifications in the appearance and...
composition of the natural potential vegetation and its substitution stages caused by climatic, edaphic, geographic and anthropogenic factors, is making possible and easier to recognize the bioclimatic and vegetational frontiers with greater precision and objectivity. Once the bounds of the vegetation series (sigmetum), geoseries (geosigmetum), permaseries (permasigmetum) and geopermaseries (geopermasigmetum) are known, as well as the bioindicator species, it is possible to calculate the numerical bioclimatic threshold values that distinguish them. This spaces corresponding to the bioclimatic units (bioclimates, thermotypes, ombrotypes and continentality: isobioclimates and meroisobioclimates) have been progressively delimited and adjusted. The obtained biophysical models have demonstrated a high level of reciprocity in the relationship between climate-vegetation distribution, which is making it possible to create bioclimatic and biogeographic maps of the world significantly more precise. One practical consequence is to have achieved a reciprocal predictive value in all Earth, only knowing the climatic and bioclimatic data to infer the vegetation types and bioindicators.

Biogeography is the science that study the distribution of species, plant communities, habitats, biocoenosis, ecosystems, biomes and bioregions on Earth, as well as the relationships between them and their conditions. It takes into account the areas of taxa and syntaxa (chorology), in addition to information from other natural sciences (geography, botany, synecology, soil science, bioclimatology, geology, etc.), and attempts to establish a hierarchical biogeographic typology of the land territories on the planet. The main systematic units in decreasing ranks are: kingdom, region, province, sector, district, country, landscape cell and tesela (RIVAS-MARTÍNEZ & AL., 2007, 2011b, 2014). Terrestrial biogeography has been twinned with phytogeography due to the value of vascular plant species and communities in its definition and delimitation on Earth.

The elementary biogeographic terrestrial unit of the lowest rank is the tesela, defined as a geographic space with a greater or lesser extension homogeneous, that means, has only a single type of potential natural vegetation (climax) and a single sequence of substitution communities. The permatesela, conceived within the framework of dynamic-catenal phytosociology, is located in exceptional sites: polar, fluvial, lake and marine landscapes, deserts, high mountain summits, dunes, rock formations, coastal cliffs, etc., in which the permanent unistrata long lasting vascular vegetation growing in these elementary spaces lacks of other type of perennial vascular substitution communities. The tesela and permatesela are the only biogeographical units which can be repeated disjointed. The landscape cells are constituted by a group of teselas or permateselas and their corresponding complexes, assembled by networks of geosigmeta and geopermasigmeta based on the geomorphology and soils of one small or big territory. The biogeographical country, district, sector and provinces are the most used types. The province is a vast geographic territory which, as well as possessing a large number of endemisms and differential species (its own subelement), has particular macroseries. It is also characteristic of each biogeographical province to hold geomacroseries and a particular altitudinal vegetation zonation or exclusive geoclines. The region is a very extensive territory, formed by a group of biogeographical provinces which has a flora or regional floristic element with species, genera or even endemic families; in addition it has its own particular megaseries, geomegaseries and geomega-permaseries and in consequence, its own bioclimatic and vegetation belts (RIVAS-MARTÍNEZ, 2005a). Finally, the kingdom is the supreme unit of biogeography, generally pluricontinental and multinsular, which in addition to taxonomic and ecosystematic considerations, addresses the origins of the flora and fauna, as well as the origin of the great continents, orogenies and particular macrobioclimates.
The Sierra Nevada National Park is located in the Penibetic Range, which runs along the provinces of Granada and Almería (Andalucía) (figure 1). Its total area is 172238 ha, of which 85883 ha belongs to more protected zone of the National Park and 86355 ha to the Peripheral Protection Area (Prepark). It stretches from NE to SW from 37º15’N in Lugros, in the Marquesado de Zenete (province of Granada), to 36º55’N in Lanjarón (also province of Granada), above the Guadalfeo river; and from E to W, it stretches from 2º35’W at the confluence of rivers Nacimiento and Andarax (province of Almería), to 3º38’W near Padul and the Vega de Granada. Its altitude ranges between 300 m in Terque, next to Andarax river (province of Almería) to 3479 m in Mulhacén peak, located in western Sierra Nevada (43b. High Nevada Sierran District), here there are other significant peaks over 3000m like: Pico del Caballo (3013m), Tosal del Cartujo (3152m), Veleta (3396m), Los Machos (3327m), Mulhacén (3479m), Alcazaba (3366m), Cuervo (3152m), Picón de Jéres (3094m) and Horcajo (3182m). The most important rivers born in the Sierra Nevada National Park are, at the North: Abrucena, Nacimiento, Huéneja, Verde, Alhama, Maitena and Genil; at the West: Monachil, Dilar, Dúrcal and Torrente; and at the South: Chico de Ohanes, Andarax, Paterna, Grande de Cherín, Netchite, Mecina, Guadalfeo (Grande de Béchules), Trevélez, Poqueira, Chico de Órgiva and Lanjarón. Only few small villages are inhabited inside the Peripheral Protection Area of the Sierra Nevada National Park (Prepark). Some of them are located at the Nacimiento and Andarax river basins, like Abrucena, Abla, Ocaña, Alboloduy, Terque, Bentarique, Canjáyar, Ohanes, Padules, Almócita and Beires; at the Grande de Cherín and Adra river basins, there are villages as Júbar and Netchite; at the Guadalfeo river basin, Béchules, Trevélez, Pampaneira, Bubión and Capileira; and finally, at the Monachil river basin, the Pradollano ski station and nearer Granada, the Cumbres Verdes residential area, placed on the mount of La Zubia.

According to MARTÍN & AL. (2008), the Penibetic Range, and specially its core, Sierra Nevada, belong mainly to the Nevado-Filábride Complex. It is formed by several overlapping tectonic units (>250Myr); graphitoïd and dark mica schists, prevail in the upper one, called Veleta, while clear mica schists predominate in the upper one, called Mulhacén. All of them are mixed with gneissic igneous acid and, above all, by the basic ultramafic rocks: peridotites, serpentinites and amphibolites. The Triassic Alpujarride complex (210-240Myr), named "El Calar", is located above and around the central core, in which marbles, limestones and dolomites are very common, as well asphylites or launas at the base. This complex, rejuvenated during the Alpine Orogeny, is surrounded by plains, valleys and quite deep detrital deposits of different thicknesses (sand, silt and conglomerates), originated during the Miocene-Quaternary age (<20 Myr).

The geomorphology in the higher central area of High Nevada Sierran District (called "La Lastra") is the result of the Wurm glaciation and, recently, the Little Ice Age. Due to the altitude and latitude of Sierra Nevada, glacier ice and permanent snow were mainly accumulated around the peaks. So, excavations made by ice and snow created numerous glacial cirques and basins along the highest peaks axis of this district, from the Cerro del Caballo (3013m) to the Horcajo de Trevélez (3182m). Also, when glaciers went down the hills, they turned into rivers or glacier tongues and formed narrow U-shaped valleys and fluted and polished rocks (GÓMEZ ORTIZ ET AL. 2002). According to GÓMEZ ORTIZ & AL. (2012), JIMÉNEZ MORENO & AL. (2012) and OLIVA & AL. (2010, 2011, 2012), the main glacier, climatic and anthropogenic events can be summarized in table I. Nowadays, Sierra Nevada plays a decisive role in the regional climate context of the peninsular south. This fact is due to its orientation and complex orography, as well as to the confluence of two models of atmospheric variability or atmospheric teleconnection patterns: the NAO (North Atlantic Oscillation) and the WeMO (Western Mediterranean Oscillation) (OLIVA & MORENO 2008).


A review and study about the plant communities in Sierra Nevada National Park (including the Prepark) has been performed, according to classical phytosociological methodology (GEHU & RIVAS-MARTÍNEZ 1981, CAPELO 2003, etc.) and dynamic-catenal phytosociology (RIVAS-MARTÍNEZ 2005b). A total of 73 orders, 118 alliances and 204 associations as well as one vegetation geoseris of (tables II and III) have been identified in the Park. Methodologically, we follow the criteria used by RIVAS-MARTÍNEZ & AL. (2011b). The nomenclature is according to MARTÍN & AL. (2005b).
Table II. Climatophilous and edafoxerophilous sigmetum, permasigmetum and synvariants of Sierra Nevada National Park

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<thead>
<tr>
<th>Climatophilous and edafoxerophilous geoparamsigmetum, sigmetum and synvariants</th>
<th>40c</th>
<th>42a</th>
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<td>Erigeron frigidii-Festuco-Gerresigmetum Clementei. (12e) (49.1.1)</td>
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<td>Daphne hispanicae-Pinosigmetum nevadensis. (14b) (74.1.1)</td>
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<td>Avenello ibericae-Pinosigmetum nevadensis. (14k) (74.4.7)</td>
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<td>Genistro vers.-Junipersigmetum hemisphaericae syn. silicceous typical with Cytisus nevadensis. (13fa) (74.6.1)</td>
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<td>Genistro vers.-Junipersigmetum hemisphaericae syn. máfica with Juniperus sabina. (13fb) (74.6.1)</td>
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<td>Pinosigmetum acutisquamae syn. trevenquina supramediterranean with Pinus latisquama. (14ib) (74.9.1)</td>
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<td>Rhamno myrtifolii-Junipersigmetum turbinatae. (14m) (74.9.2)</td>
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<td>Adenocarpo decorticantis-Quercosigmetum rotundifolii synv. typ.</td>
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<td>Supramediterranean of Adenocarpus decort. (24da) (75.2.8)</td>
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<td>Adenocarpo decorticantis-Quercosigmetum rotundifolii synv. mesomediterranean of Retama sphaerocarpa. (24db) (75.2.8)</td>
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<td>Berberido hisp.-Quercosigmetum rotundifolii synv. batophilous of Berberis hispanica. (24fa) (75.2.9)</td>
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<td>Berberido hisp.-Quercosigmetum rotundifolii synv. bética granadina</td>
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<td>calco-dolomiticolois of Lavandula lanata. (24e) (75.2.9)</td>
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<td>Berberido hisp.-Quercosigmetum rotundifolii synv. east penibetic of Prunas ramarius. (24f) (75.2.9)</td>
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<td>Paeonio coriaceae-Quercosigmetum rotundifolii synv. typical</td>
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<td>upper mesomediterranean of Quercus coccifera. (24ea) (75.2.14)</td>
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<td>Paeonio coriaceae-Quercosigmetum rotundifolii synv. thermophilus of Pistacia lentiscus. (24eb) (75.2.14)</td>
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<td>Paeonio coriaceae-Quercosigmetum rotundifolii synv. Guadix-Baza sector of Genista pumila. (24ec) (75.2.14)</td>
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<td>Paeonio coriaceae-Quercosigmetum rotundifolii synv. penibetic alminerense of Phlomis almeriensis. (24ed) (75.2.14)</td>
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<td>Rhamno myrtifolii-Quercosigmetum rotundifolii (24a) (75.3.7)</td>
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<td>Rhamno oles-Quercosigmetum rotundifolii synv. alpujarras-almijara calco-dolomiticolois of Rhamnus velutina (27bb) (75.3.7)</td>
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<td>Rhamno oleoidis-Quercosigmetum rotundifolii synv. Gador sierran of Phlomis almeriensis. (27bd) (75.3.7)</td>
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<td>Chamaeropa humilis-Rhamnosigmetum lycoidis synv. West</td>
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<td>Almeria of Phlomis almeriensis. (31ab) (75.5.10)</td>
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<td>Ephedro fragilis-Pinosigmetum halepensis synv. upper mesomediterranean of Genista pumila. (29b) (75.7.24.)</td>
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<td>Rhamno almeriensis-Pinosigmetum halepensis. (29k) (75.7.25.)</td>
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<td>Brachypodio boissieri-Pinosigmetum halepensis. (29h) (75.7.27.)</td>
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<td>Zicophisigmetum loti synv. tabernese loamy of Eucromodendron bourgeanae (32bc) (75.8.4)</td>
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<td>Adenocarpo decorticantis-Quercosigmetum pyrenaeicae synv. typical</td>
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<td>Nevada Sier. (18ga) (76.7.1)</td>
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<td>Berberido hispanicae-Acerisigmetum granatensis. (19o) (76.10.14)</td>
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<td>Salici capreae-Betulosigmetum fontqueri. (7m) (76.14.9)</td>
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Besides, 36 meteorological stations within and immediately surrounding the National Park (table IV) were selected as basis of the bioclimatic study of the SNNP. Data about 31 of these stations were taken from the website "Worldwide Bioclimatic Classification System: 1996-2015", S. Rivas-Martínez & S. Rivas Sáenz, Phytosociological Research Center, Spain: (http://www.globalbioclimatics.org). Data about other three stations (Aljibe Montenegro, El Encinar and Piedra de los Soldados), with few years of observation, were taken from the National Parks Network (Sierra Nevada Global Change Observatory). The second data station of Sierra Nevada, A U, 2510 m, are from GÓMEZ ORTIZ & AL.(2002: 68, tb 9). The data IRAM are from the Institut of Radioastronomie Millimétrique, whose telescope is located no to far from the Veleta peak (2860m). Data were treated according to the bioclimatic classification system proposed by RIVAS-MARTíNEZ (2007, RIVAS-MARTíNEZ & AL. 2011a), and different indexes were obtained. They are shown in table IV.

An essential feature of the mediterranean macrobioclimate is the existence of aridity at least two months during the summer, that meaning that the monthly precipitation is less than twice the average temperature (Pi/Ti ≤ 2), where Pi is the average monthly rainfall and Ti is the average monthly temperature. The fact that Sierra Nevada is the only europaean high mountain with a mediterranean climate from its base to the highest levels, has led us to consider how and to what extent this aridity is suffered indifferent territories of the SNNP. In collaboration with Rivas-Martinez, we have developed two new indexes: Annual Aridity Index (Vaa) and Summer Aridity Index (Vas).
Table III. Edaphohygrophilous sigmetum, geosigmetum and synvariants of Sierra Nevada National Park

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<thead>
<tr>
<th>Edaphohygrophilous sigmetum, geosigmetum and synvariants</th>
<th>40c</th>
<th>42a</th>
<th>43a</th>
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<tr>
<td>Saccharo ravenae-Tamaricisigmetum canariensis sv. typical hard water with Arum italicum (39m) (70.1.8)</td>
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<td>Saccharo rav.-Tamaricisigmetum canariensis syn. oligohaline waters with Tamarix canariensis (39mb) (70.1.8)</td>
<td>●</td>
<td>●</td>
<td>-</td>
<td>-</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Rubo ulmifoli-Neriosigmetum oleandri (39k) (70.4.4)</td>
<td>-</td>
<td>-</td>
<td>●</td>
<td>-</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Zizipho loti-Neriosigmetum oleandri (39o) (70.4.6)</td>
<td>●</td>
<td>●</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Nerio oleandri-Populogoosigmetum albae synv. typical of Nerium oleander (36a, 61ga) (71.2.4.)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Nerio oleandri-Populogoosigmetum albae synv. oligohaline of Tamarix canariensis (36db, 61gb) (71.2.4)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
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<tr>
<td>Lonicero biflorae-Populogoosigmetum albae (36j, 61j) (71.2.20)</td>
<td>●</td>
<td>●</td>
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<td>-</td>
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<tr>
<td>Aceri granatensis-Praxinosigmetum angustifoliae (36k) (71.2.10)</td>
<td>-</td>
<td>-</td>
<td>●</td>
<td>●</td>
<td>-</td>
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</tr>
<tr>
<td>Crataego granat.-Salicisigmetum neotrichae sv. Granada vega &amp; Guadix of Salix alba (36uc, 61kc) (71.2.24)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>●</td>
<td>●</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Crataego granatensis-Salicisigmetum neotrichae synv. mesop - supramediterranean of Praxinos angustifoliae. (36ud, 61kd) (71.2.24)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>●</td>
<td>●</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Carici camposii-Salicisigmetum trocineriae (37j, 62j) (71.3.11)</td>
<td>-</td>
<td>-</td>
<td>●</td>
<td>●</td>
<td>-</td>
<td>-</td>
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<td>-</td>
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<tr>
<td>Heracleo granatensis-Albagoosigmetum glutinosae (37a, ) (62j) (71.3.16)</td>
<td>-</td>
<td>-</td>
<td>●</td>
<td>●</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Dorycnio recti-Salicisigmetum pedicellatae (38v) (71.9.4)</td>
<td>-</td>
<td>-</td>
<td>●</td>
<td>●</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Erico terminalis-Saliciminorisigmetum angustifoliae (38k) (71.9.6)</td>
<td>-</td>
<td>-</td>
<td>●</td>
<td>●</td>
<td>-</td>
<td>-</td>
<td>-</td>
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</tr>
</tbody>
</table>

Vas (summer aridity index) is the numerical value resulted by the addition of de value each summer month: \(I_{o_{6}} = \text{june}, I_{o_{7}} = \text{july}, I_{o_{8}} = \text{august}, \) when the monthly \(I_{o} < 2.0; \) \(Vas = \sum_{200}^{300} (RIVAS-MARTÍNEZ & AL. 2011b), \) we performed the distribution of the different vegetation series and perma - summer, due to a very low humidity on the air. The application of the monthly ombrothermic indexes is particularly interesting in the Sierra Nevada highest mountains, particularly during the cold frigide months, with an average temperature equal or below zero degrees celsius (\( \text{Tp} \leq 0 \)). Given the extreme low of summer rain and the water unavailability in the frozen months; only permit grow and survive in the dry ombroclime, even when there are plenty of winter snow in the peaks but that melt and sublimate very quickly, in early summer, due to a very low humidity on the air.

The application of the monthly ombrothermic indexes is particularly interesting in the Sierra Nevada highest mountains, particularly during the cold frigide months, with an average temperature equal or below zero degrees celsius (\( \text{Tp} \leq 0 \)). Given the extreme low of summer rain and the water unavailability in the frozen months; only permit grow and survive in the dry ombroclimate, even when there are plenty of winter snow in the peaks but that melt and sublimate very quickly, in early summer, due to a very low humidity on the air.

Results and discussion

After estimating climate data and comparing with the distribution of the different vegetation series and perma series (RIVAS-MARTÍNEZ & AL. 2011b), we performed the thermotypes map (figure 2) and the ombrotypes map (figure 3) as a result of a process of identification and location of associations and vegetation series, in relation with the bioclimatic conditions. Following this way, we have established the existence of five thermotypes and four ombrotypes in the Sierra Nevada National Park. Although the official SNNP extension is 172238ha, according to the maps of the Park, made and published by the Environmental Information Network (REDIAM, Junta de Andalucía), the estimated surface is 171915.61ha. Taking this data as a basis, we have obtained the surface of each thermotype and ombrotype and their percentage of the total, which is shown in table VI. The altitudinal amplitude reached by each thermotype has also been estimated, in this case according to the maps of the Park, made and published according to the bioclimates of Sierra Neveda National Park, belonging to five sectors and two biogeographic provinces (figure 5), whose surface representation is shown in table VIII.

<table>
<thead>
<tr>
<th>Ombroclimate summer</th>
<th>Vas values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultrahyperatear</td>
<td>540-600</td>
</tr>
<tr>
<td>Hyperarid</td>
<td>480-540</td>
</tr>
<tr>
<td>Lower arid</td>
<td>390-480</td>
</tr>
<tr>
<td>Upper arid</td>
<td>300-390</td>
</tr>
<tr>
<td>Lower semiard</td>
<td>150-300</td>
</tr>
<tr>
<td>Upper semiard</td>
<td>1-150</td>
</tr>
</tbody>
</table>

The application of the monthly ombrothermic indexes is particularly interesting in the Sierra Nevada highest mountains, particularly during the cold frigide months, with an average temperature equal or below zero degrees celsius (\( \text{Tp} \leq 0 \)). Given the extreme low of summer rain and the water unavailability in the frozen months; only permit grow and survive in the dry ombroclimate, even when there are plenty of winter snow in the peaks but that melt and sublimate very quickly, in early summer, due to a very low humidity on the air.

Table V. Summer Aridity Index (Vas): units and values

<table>
<thead>
<tr>
<th>Ombroclimate summer</th>
<th>Vas values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultrahyperatear</td>
<td>540-600</td>
</tr>
<tr>
<td>Hyperarid</td>
<td>480-540</td>
</tr>
<tr>
<td>Lower arid</td>
<td>390-480</td>
</tr>
<tr>
<td>Upper arid</td>
<td>300-390</td>
</tr>
<tr>
<td>Lower semiard</td>
<td>150-300</td>
</tr>
<tr>
<td>Upper semiard</td>
<td>1-150</td>
</tr>
</tbody>
</table>

The application of the monthly ombrothermic indexes is particularly interesting in the Sierra Nevada highest mountains, particularly during the cold frigide months, with an average temperature equal or below zero degrees celsius (\( \text{Tp} \leq 0 \)). Given the extreme low of summer rain and the water unavailability in the frozen months; only permit grow and survive in the dry ombroclimate, even when there are plenty of winter snow in the peaks but that melt and sublimate very quickly, in early summer, due to a very low humidity on the air.

Table VI. Surface (ha) and percentage covers (%) of thermotypes and ombrotypes in SNNP.

<table>
<thead>
<tr>
<th>Thermotypes</th>
<th>Surface (ha)</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cryomediterranean</td>
<td>3571.79</td>
<td>2.1</td>
</tr>
<tr>
<td>Oromediterranean</td>
<td>35477.81</td>
<td>20.6</td>
</tr>
<tr>
<td>Supramediterranean</td>
<td>78791.63</td>
<td>45.8</td>
</tr>
<tr>
<td>Mesomediterranean</td>
<td>46438.55</td>
<td>27.0</td>
</tr>
<tr>
<td>Thermomediterranean</td>
<td>7639.41</td>
<td>4.5</td>
</tr>
<tr>
<td>Total</td>
<td>171915.61</td>
<td>100.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ombrotypes</th>
<th>Total (ha)</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subhumid</td>
<td>128858.77</td>
<td>75.0</td>
</tr>
<tr>
<td>Dry (cryogenic)</td>
<td>5588.68</td>
<td>3.2</td>
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<tr>
<td>Dry</td>
<td>23779.93</td>
<td>13.8</td>
</tr>
<tr>
<td>Semiard</td>
<td>9456.94</td>
<td>5.5</td>
</tr>
<tr>
<td>Upper Arid</td>
<td>4231.27</td>
<td>2.5</td>
</tr>
<tr>
<td>Total</td>
<td>171915.61</td>
<td>100.0</td>
</tr>
</tbody>
</table>
Table IV. Bioclimatic data of Sierra Nevada National Park

<table>
<thead>
<tr>
<th>Localities</th>
<th>Latd. &amp; Longt.</th>
<th>Alt (m)</th>
<th>Ty</th>
<th>Py</th>
<th>T</th>
<th>Tp</th>
<th>Pp</th>
<th>Ite</th>
<th>Ic</th>
<th>Io</th>
<th>Ios₂</th>
<th>Ios₃</th>
<th>Vas</th>
<th>Vaa</th>
<th>P&lt;2T</th>
<th>Tp</th>
<th>Ts</th>
<th>Years</th>
<th>Seasonal rhythms</th>
<th>Isobioclimates</th>
</tr>
</thead>
<tbody>
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<td>Orgiva</td>
<td>36º 54'N 3º 25'W</td>
<td>450</td>
<td>39</td>
<td>30</td>
<td>16.5</td>
<td>476</td>
<td>352</td>
<td>15.1</td>
<td>2.40</td>
<td>0.15</td>
<td>0.27</td>
<td>516</td>
<td>653</td>
<td>5</td>
<td>1978</td>
<td>701</td>
<td>1953-1991</td>
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</tr>
<tr>
<td>Alboloduy</td>
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<td>28</td>
<td>17.7</td>
<td>241</td>
<td>389</td>
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<td>1.14</td>
<td>0.12</td>
<td>0.18</td>
<td>546</td>
<td>898</td>
<td>9</td>
<td>2119</td>
<td>745</td>
<td>1965-1992</td>
<td>W&gt;F&gt;P&gt;F</td>
<td>Up. thermomed. low semiarid</td>
<td></td>
</tr>
<tr>
<td>Canjáyar</td>
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<td>610</td>
<td>21</td>
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<td>374</td>
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<td>1.65</td>
<td>0.18</td>
<td>0.29</td>
<td>511</td>
<td>649</td>
<td>5</td>
<td>2127</td>
<td>783</td>
<td>1951-1990</td>
<td>W&gt;F&gt;P&gt;P</td>
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<tr>
<td>Armilla</td>
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<td>40</td>
<td>15.3</td>
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<td>18.9</td>
<td>2.18</td>
<td>0.18</td>
<td>0.28</td>
<td>514</td>
<td>621</td>
<td>4</td>
<td>1837</td>
<td>723</td>
<td>1931-1970</td>
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</tr>
<tr>
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<td>54</td>
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<td>585</td>
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<td>641</td>
<td>1946-1999</td>
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<td>1848</td>
<td>719</td>
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<tr>
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<tr>
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<td>661</td>
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<tr>
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<td>565</td>
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<td>1802</td>
<td>697</td>
<td>1951-1992</td>
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<td>1708</td>
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<td>1961-1991</td>
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<td>1951-1992</td>
<td>W&gt;F&gt;P&gt;S</td>
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<td>668</td>
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<td>1717</td>
<td>704</td>
<td>1966-1999</td>
<td>F&gt;W&gt;P&gt;S</td>
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<td>627</td>
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<td>1829</td>
<td>675</td>
<td>1953-1996</td>
<td>W&gt;F&gt;P&gt;S</td>
<td>Low mesomed. low dry</td>
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</tr>
<tr>
<td>P. Quéntar</td>
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<td>500</td>
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<td>1639</td>
<td>657</td>
<td>1959-1992</td>
<td>W&gt;F&gt;P&gt;S</td>
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<td>7</td>
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<td>714</td>
<td>2008-2014</td>
<td>W&gt;F&gt;P&gt;S</td>
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<td>0.46</td>
<td>453</td>
<td>611</td>
<td>4</td>
<td>1637</td>
<td>647</td>
<td>1954-1992</td>
<td>W&gt;F&gt;P&gt;S</td>
<td>Up. mesomed. low subhumid</td>
<td></td>
</tr>
</tbody>
</table>
Table IV. Bioclimatic data of Sierra Nevada National Park

<table>
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<tr>
<th>Localities</th>
<th>Latd. &amp; Longt.</th>
<th>Alt (m)</th>
<th>Ty</th>
<th>Py</th>
<th>T</th>
<th>Pp</th>
<th>Itc</th>
<th>Io</th>
<th>Isos$_{2}$</th>
<th>Isos$_{3}$</th>
<th>Vas</th>
<th>Vaa</th>
<th>P&lt;2T</th>
<th>Tp</th>
<th>Ts</th>
<th>Years</th>
<th>Seasonal rhythms</th>
<th>Isobioclimates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ohanes Centr.</td>
<td>37° 2' N 2° 44' W</td>
<td>1000</td>
<td>34</td>
<td>28</td>
<td>14.9</td>
<td>385</td>
<td>294</td>
<td>17.6</td>
<td>2.15</td>
<td>0.15</td>
<td>0.28</td>
<td>512</td>
<td>646</td>
<td>5</td>
<td>1794</td>
<td>700</td>
<td>1963-1996</td>
<td>W&gt;F&gt;P&gt;S</td>
</tr>
<tr>
<td>Pampaneira</td>
<td>36°56' N 3° 21' W</td>
<td>1000</td>
<td>26</td>
<td>21</td>
<td>14.5</td>
<td>666</td>
<td>302</td>
<td>15.2</td>
<td>3.83</td>
<td>0.20</td>
<td>0.37</td>
<td>462</td>
<td>506</td>
<td>4</td>
<td>1742</td>
<td>653</td>
<td>1967-1992</td>
<td>W&gt;F&gt;P&gt;S</td>
</tr>
<tr>
<td>Cañar Jarales</td>
<td>36° 55' N 3° 25' W</td>
<td>1071</td>
<td>46</td>
<td>38</td>
<td>13.3</td>
<td>591</td>
<td>255</td>
<td>17.2</td>
<td>3.69</td>
<td>0.21</td>
<td>0.38</td>
<td>477</td>
<td>641</td>
<td>4</td>
<td>1600</td>
<td>652</td>
<td>1951-1999</td>
<td>W&gt;P&gt;F&gt;S</td>
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<td>La Peza</td>
<td>37° 16' N 3°17'W</td>
<td>1085</td>
<td>42</td>
<td>42</td>
<td>13.1</td>
<td>456</td>
<td>236</td>
<td>16.4</td>
<td>2.90</td>
<td>0.25</td>
<td>0.49</td>
<td>446</td>
<td>537</td>
<td>4</td>
<td>1573</td>
<td>616</td>
<td>1951-1992</td>
<td>W&gt;P&gt;F&gt;S</td>
</tr>
<tr>
<td>C. Guadix</td>
<td>37° 13' N 3° 9' W</td>
<td>1135</td>
<td>10</td>
<td>38</td>
<td>13.0</td>
<td>410</td>
<td>240</td>
<td>16.6</td>
<td>2.63</td>
<td>0.42</td>
<td>0.69</td>
<td>386</td>
<td>470</td>
<td>4</td>
<td>1559</td>
<td>610</td>
<td>1951-1992</td>
<td>P&gt;W&gt;F&gt;S</td>
</tr>
<tr>
<td>Jéres del M.</td>
<td>37° 11' N 3° 9' W</td>
<td>1223</td>
<td>10</td>
<td>42</td>
<td>12.8</td>
<td>377</td>
<td>236</td>
<td>16.3</td>
<td>2.46</td>
<td>0.41</td>
<td>0.60</td>
<td>410</td>
<td>494</td>
<td>4</td>
<td>1531</td>
<td>610</td>
<td>1951-1992</td>
<td>P&gt;W&gt;F&gt;S</td>
</tr>
<tr>
<td>Capileira</td>
<td>36° 57' N 3° 9' W</td>
<td>1236</td>
<td>75</td>
<td>37</td>
<td>13.2</td>
<td>830</td>
<td>250</td>
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<td>0.36</td>
<td>365</td>
<td>365</td>
<td>3</td>
<td>1582</td>
<td>623</td>
<td>1918-1992</td>
<td>W&gt;P&gt;F&gt;S</td>
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<tr>
<td>Aldeire</td>
<td>37° 9' N 3° 4' W</td>
<td>1277</td>
<td>19</td>
<td>42</td>
<td>12.2</td>
<td>356</td>
<td>222</td>
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<td>2.43</td>
<td>0.40</td>
<td>0.62</td>
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<td>487</td>
<td>4</td>
<td>1466</td>
<td>610</td>
<td>1951-1992</td>
<td>P&gt;W&gt;F&gt;S</td>
</tr>
<tr>
<td>Huéneja</td>
<td>37° 9' N 2° 57' W</td>
<td>1278</td>
<td>22</td>
<td>33</td>
<td>12.3</td>
<td>439</td>
<td>221</td>
<td>17.2</td>
<td>2.98</td>
<td>0.27</td>
<td>0.45</td>
<td>455</td>
<td>510</td>
<td>4</td>
<td>1472</td>
<td>614</td>
<td>1958-1990</td>
<td>W&gt;F&gt;P&gt;S</td>
</tr>
<tr>
<td>Laujar Monte.</td>
<td>37° 1' N 2° 53' W</td>
<td>1280</td>
<td>50</td>
<td>50</td>
<td>13.0</td>
<td>599</td>
<td>252</td>
<td>16.5</td>
<td>3.84</td>
<td>0.34</td>
<td>0.52</td>
<td>434</td>
<td>475</td>
<td>4</td>
<td>1560</td>
<td>630</td>
<td>1950-1999</td>
<td>W&gt;F&gt;P&gt;S</td>
</tr>
<tr>
<td>Béchules</td>
<td>36° 58' N 3° 11' W</td>
<td>1319</td>
<td>19</td>
<td>32</td>
<td>12.5</td>
<td>683</td>
<td>233</td>
<td>16.7</td>
<td>4.56</td>
<td>0.20</td>
<td>0.50</td>
<td>436</td>
<td>480</td>
<td>4</td>
<td>1496</td>
<td>613</td>
<td>1961-1992</td>
<td>W&gt;F&gt;P&gt;S</td>
</tr>
<tr>
<td>Soportújar</td>
<td>36° 56' N 3° 24' W</td>
<td>1400</td>
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<td>26</td>
<td>13.0</td>
<td>740</td>
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<td>17.1</td>
<td>4.76</td>
<td>0.13</td>
<td>0.38</td>
<td>474</td>
<td>544</td>
<td>4</td>
<td>1556</td>
<td>628</td>
<td>1944-1969</td>
<td>W&gt;F&gt;P&gt;S</td>
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<tr>
<td>El Encinar</td>
<td>37° 5' N 2° 57' W</td>
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<td>7</td>
<td>11.2</td>
<td>390</td>
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<td>18.2</td>
<td>2.90</td>
<td>0.19</td>
<td>0.35</td>
<td>491</td>
<td>627</td>
<td>6</td>
<td>1343</td>
<td>605</td>
<td>2008-2014</td>
<td>W&gt;F&gt;P&gt;S</td>
</tr>
<tr>
<td>Laujar Cerec.</td>
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<td>5.61</td>
<td>0.43</td>
<td>0.80</td>
<td>341</td>
<td>342</td>
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<td>1227</td>
<td>541</td>
<td>1951-1991</td>
<td>W&gt;F&gt;P&gt;S</td>
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<td>P. Soldados</td>
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<td>2155</td>
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<td>7</td>
<td>7.7</td>
<td>546</td>
<td>85</td>
<td>18.3</td>
<td>5.40</td>
<td>0.25</td>
<td>0.55</td>
<td>416</td>
<td>416</td>
<td>3</td>
<td>921</td>
<td>495</td>
<td>2008-2014</td>
<td>F&gt;W&gt;P&gt;S</td>
</tr>
<tr>
<td>S. Nevada A.</td>
<td>37° 5' N 3° 23' W</td>
<td>2507</td>
<td>15</td>
<td>15</td>
<td>3.9</td>
<td>693/290</td>
<td>-34</td>
<td>21.0</td>
<td>4.91</td>
<td>0.56</td>
<td>1.14</td>
<td>265</td>
<td>265</td>
<td>2</td>
<td>589</td>
<td>417</td>
<td>1975-1989</td>
<td>W&gt;F&gt;P&gt;S</td>
</tr>
<tr>
<td>S. Nevada A.</td>
<td>37° 5' N 3° 23' W</td>
<td>2510</td>
<td>12</td>
<td>12</td>
<td>4.4</td>
<td>776/324</td>
<td>-38</td>
<td>18.8</td>
<td>5.20</td>
<td>0.49</td>
<td>1.96</td>
<td>245</td>
<td>245</td>
<td>2</td>
<td>619</td>
<td>398</td>
<td>1973-1992</td>
<td>W&gt;F&gt;P&gt;S</td>
</tr>
<tr>
<td>Veleta IRAM</td>
<td>37° 4' N 3° 23' W</td>
<td>2860</td>
<td>20</td>
<td>-</td>
<td>-55</td>
<td>16.9</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>473</td>
<td>337</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1985-2004</td>
<td>-</td>
</tr>
</tbody>
</table>
Table VII. Altitudinal thermic boundaries of the thermotypes in Sierra Nevada National Park.

<table>
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<tr>
<th>Thermotype altitudinal boundaries</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest summits</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oromediterranean/cryomediterranean</td>
<td>2950m-2900m</td>
<td>2900m-2950m</td>
<td>2950m-3050m</td>
<td>3100m-3150m</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Supramediterranean/oromediterranean</td>
<td>2150m-2250m</td>
<td>2050m-2150m</td>
<td>2150m-2250m</td>
<td>2200m-2350m</td>
<td>2200m-2350m</td>
<td>2300m-2400m</td>
<td>-</td>
</tr>
<tr>
<td>Mesomediterranean/supramediterranean</td>
<td>1250m-1300m</td>
<td>1300m-1350m</td>
<td>1200m-1300m</td>
<td>1400m-1450m</td>
<td>1450m-1500m</td>
<td>1500m-1550m</td>
<td>1500m-1550m</td>
</tr>
<tr>
<td>Thermomediterranean/mesomediterranean</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>(550m)</td>
<td>(700m)</td>
<td>700m-800m</td>
<td>700m-750m</td>
</tr>
<tr>
<td>Slopes</td>
<td>N</td>
<td>NW</td>
<td>W</td>
<td>SW</td>
<td>S (central)</td>
<td>SE</td>
<td>E</td>
</tr>
<tr>
<td>Main river</td>
<td>Guadix</td>
<td>Genil</td>
<td>Dúrcal</td>
<td>Guadalfeo</td>
<td>Grande</td>
<td>Andarax</td>
<td>Nacimiento</td>
</tr>
</tbody>
</table>


The analysis of obtained data indicates that the whole National Park is a mediterranean territory, from a bioclimatic point of view. It has a widespread summer drought, mitigated in the highest areas, with the exception of the peaks, due to, at summits over 2900-2950m altitude correspond to the semiarid value.

The obtained increase of precipitations. The implementation of the Summer Aridity Index (Vas) indicates that the summer aridity is extreme in almost the whole territory, with summer ombroclimates reaching near the ultrahyperarid value in the lowest eastern areas. However, the most widespread value is the hyperarid value, which only reaches the lowest value in those areas facing the Mediterranean Sea or in closed valleys. Under these circumstances, only two stations come to reach the upper arid value, and only the two highest stations have a lower semiarid ombroclimate during two months of the summer. It is not possible for us to obtain a detailed aridity degree in heights over 2500m due to the lack of data. Nevertheless, using data collected from Sierra Nevada-Albergue Universitario and Veleta IRAM stations, we deduce that thermotype distribution allows us to recognize the thermomediterranean climate belt only at the eastern area, at the confluence of the Andarax and Nacimiento rivers. (figure 2) This area has an extension equal to 4.5% of the SNNP, reaching 700-800m height at the Nacimiento and Andarax rivers basins, that it is the warmest area and also the driest one. It is barely present on the rest of the territory, only in some zones to the S and SW.
The bioclimates of Sierra Neveda National Park

Table VIII. Surface (ha) and percentage covers (%) of biogeographic districts in Sierra Nevada National Park

<table>
<thead>
<tr>
<th>Districts</th>
<th>Surface (ha)</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40c. West Almeria</td>
<td>4568.64</td>
<td>2.6</td>
</tr>
<tr>
<td>42a. Hoya de Guadix</td>
<td>1464.18</td>
<td>0.9</td>
</tr>
<tr>
<td>43a. East NevadaSierran</td>
<td>68015.87</td>
<td>39.5</td>
</tr>
<tr>
<td>43b. High Nevada Sierran</td>
<td>62046.95</td>
<td>36.1</td>
</tr>
<tr>
<td>44a. Gador Sierran</td>
<td>13681.65</td>
<td>8.0</td>
</tr>
<tr>
<td>44b. Alpujarras</td>
<td>2206.17</td>
<td>1.3</td>
</tr>
<tr>
<td>45a. Vega de Granada</td>
<td>795.97</td>
<td>0.5</td>
</tr>
<tr>
<td>45c. Trevenque Sierran</td>
<td>19126.14</td>
<td>11.1</td>
</tr>
<tr>
<td>Total</td>
<td>171915.61</td>
<td>100.0</td>
</tr>
</tbody>
</table>

The mesomediterranean thermotype is present all around of the National Park. The fact that Sierra Nevada heights rises steeply, makes that the area with this thermotype is not too big (27%), reaching the highest altitudes, 1500-1550m, in the Andarax and Nacimiento basins rivers. The thermotype limits are lower in other basins, descending westward: Grande de Cherín river basin until 1450-1500m, Guadalfeo until 1400-1450m and northwest: Dúrcal river basin until 1200-1300m, Genil until 1300-1350m and Guadix until 1250-1300m.

The supramediterranean thermotype occupies the largest area: 45.8%. It extends over a large ring that completely surrounds the oromediterranean one. Although, it begins at a considerable height (just where the mesomediterranean ends), it goes beyond the limits of the Park to the NW, reaching Huétor and Yedra mountains in the Alfacar district. The oromediterranean belt territory has its lowest height at 2050-2150m in the Genil river basin, then 2150-2250 in the Guadix and Dúrcal basins, 2200-2350m in the Guadalfeo and Grande basins and 2300-2400m in the Andarax river basin. The oromediterranean thermotype territory has a relative extent of 20.6%, having its greater area to the west of the National Park. Its heights reach the cryormediterranean thermotype, approximately at 2900-2950m in Genil river basin, 2950-3000m in Guadix river basin, 2950-3050m in Dúrcal river basin and even 3100-3150m in Guadalfeo river basin (South slopes of Mulhacén). The cryormediterranean thermotype, which completes the ombroclimatic serie of five thermotypes, occupies 2.1% in the National Park.

Ombrotypes bioclimatic map (figure 3) indicates the presence of subhumid type in most of the SNNP area. Up to 75% is present at heights ranging from about 900m, in the rainiest stations in the W and NW of the National Park, and reaching 2900m on the north slopes of the highest peaks. From 2900-3000m above sea level, the soil remains frozen for six to seven months a year, particularly in the north faces. Since we can only take into account the summer precipitation plus the rainfall during 1-3 months more, we must assign this territory dry ombrotpe. However, this dry ombrotpe has a specific origin, the lack of precipitation in the warmest months, we have identified 3c. Dry (cryogenic) ombrotpe, that is the only existing in the cryormediterranean belt, occupying 3.2% of the National Park.

The non-cryogenic dry ombrotpe occupies a small area, only a 13.8% at the edges of the park; the semi-arid (5.5%) and the upper arid ombrotpe (2.5%) are represented only in the eastern part of Andarax and Nacimiento rivers basins, mainly at the lowest and warmest zones. On the other hand, the lack of rainfall data in altitude prevents us in this moments state the existence of a humid ombrotpe.

The map (figure 4) shows the area in which the ground remains frozen at least for a month a year, that means that this area has no positive temperature during the frozen months.

A direct consequence of the study was the distinction between eight biogeographic districts, grouped into five sectors and two biogeographic provinces. The area occupied by each of the territories is very heterogeneous.
First, the two biogeographic provinces: Bética and Murcia and Almeria. The Bética province occupies 97.4%, while Murcia and Almeria province is restricted to the SE of the Park and occupies only a 2.6%. This small biogeographic province has only one sector, Almería, and one district: West Almeria.

The remaining sectors and districts belong to the Bética province. The largest sector is the Nevada Sierran Sector, which occupies the 75.6% of the Sierra Nevada National Park area and extends around the central core, with two districts: East Nevada Sierran District (39.5%) and High Nevada Sierran District (36.1%). The Granada and Sierra Almijara Sector is represented by two districts: Trevenque Sierran District (11.1%) and Vega de Granada District (0.5%). They occupy the western part of the park. Alpujarras and Gádor Sierran Sector, located on the southern slopes of Sierra Nevada, is also present and includes two districts: Gádor Sierran District (8%) and Alpujarras District (1.3%). Finally, the Hoyas de Guadix and Baza Sector, represents a small area at the north of the Park, with the Hoya de Guadix District (0.9%).

Figure 4. Sierra Nevada National Park. Territory with monthly average temperature below 0º C

Figure 5. Biogeographic map (provinces, sectors and districts). Sierra Nevada National Park
Acknowledgements:

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References:


Oliva, M. & Gómez Ortiz, A. 2012. Late Holocene environmental dynamics and climate variability in a Mediterranean high mountain environment (Sierra Nevada, Spain) inferred from lake sediments and historical sources. The Holocene 22 (8): 915-927.


