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MONITORING LICHENS DIVERSITY AND CLIMATIC CHANGE IN SIERRA NEVADA (SPAIN)

Seguimiento de la diversidad de líquenes y cambio climático en Sierra Nevada (España)

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ABSTRACT.– Lichens are common organisms in high mountain zones, where they play an important role in ecosystem balance. In recent years, the increasing interest in understanding more about their interactions with abiotic factors has prompted several investigations, some of which have proved their value as bioindicators of climatic conditions. In this context, focusing on climatic change effects on high mountain vascular plants and supported by the Global Observation Research Initiative in Alpine Environments project (GLORIA), we have monitored for the first time the lichens biodiversity in Sierra Nevada with the intention of studying the alterations caused by the process of climatic change.

The aim of this paper is to explain the monitoring experience developed on the massif and contribute to the first results from the biodiversity and statistical analysis of the sampling data.

Keywords: Long-term monitoring, biodiversity, climate change, Sierra Nevada, Spain.

RESUMEN.– Los líquenes son organismos comunes en las zonas de alta montaña donde juegan un importante papel en el equilibrio de los ecosistemas. En los últimos años, el creciente interés por entender más acerca de sus interacciones con los factores abióticos ha motivado diversas investigaciones, algunas de las cuales han demostrado su valor como bioindicadores de las condiciones climáticas. En este con-

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texto, centrándonos en los efectos del cambio climático en plantas vasculares de alta montaña y respaldados por el proyecto "Iniciativa para la investigación y el seguimiento global de los ambientes alpinos (GLORIA)", se ha monitorizado por primera vez la diversidad de líquenes en Sierra Nevada con la intención de estudiar las posibles alteraciones que esta pueda sufrir causadas por el proceso de cambio climático.

El objetivo de este artículo es el de dar a conocer la experiencia de seguimiento en el macizo y aportar los primeros resultados procedentes del análisis, tanto de la biodiversidad como estadístico, de los datos de muestreo.

Palabras clave: Seguimiento a largo plazo; biodiversidad; cambio climático, Sierra Nevada, España.

1. Introduction

In the last years, researches have experienced an increasingly wider interest in relation to environmental variables, specifically, some of them centred on growing lichens rates and environmental conditions such as humidity, temperature or precipitation (Innes, 1985; Sancho & Pintado, 2004; Hawksworth *et al.,* 2005). This situation has been propitiated, among other reasons, by the verification of these organisms as useful bioindicators of the climatic conditions mainly because of their nature: they are long-living organisms, sessile, sensitive to environmental influences, etc.

In relation to this, many of these scientific investigations are nowadays focused on the current global warming process, emphasizing high mountain zones as suitable environments for these researches (Grabherr *et al.,* 1994, 2001; Körner, 1994, 2002; Theurillat, 1995; Pauli *et al.,* 1996; Dullinger *et al*., 2007, Grabherr *et al*., 2010) where the study of lichens has appeared as an interesting option (Melick & Seppelt, 1997; Harrison & Winchester, 2000; Herk *et al*., 2002; Scheidegger *et al*., 2002; Vittoz *et al*., 2010). These upper zones rely on steep ecological gradients, are dominated by abiotic factor in relation to climate conditions and present less anthropogenic disturbances compared with lower altitudes (Pauli *et al.,* 2004). Additionally, these areas often possess a considerable floristic biodiversity and an endemism rate which provoke their consideration as vulnerable areas.

On this basis, the upper zone of Sierra Nevada (southern Spain) appears as one of the suitable areas where the study of global warming through lichens could be an interesting alternative as yet unconsidered. It includes prominent peculiarities such as its geographical location, type of climate (Mediterranean), high floristic biodiversity and endemism rate which marks its importance at national and international level (Quézel, 1953; Werner, 1979; Molero Mesa & Pérez Raya, 1987, Molero Mesa *et al.,* 1996; Blanca & Molero

Mesa, 1990; Rivas-Martínez *et al.,* 1991; Blanca *et al.*, 1998; Myers *et al.*, 2000), and its consideration as one of the most sensible and vulnerable zones to climate change effects in the Iberian Peninsula (Fernández González *et al.*, 2005).

This has been some of the motivation for why several projects about climatic change effects, at different levels, have already been developed on this area. One of them, the European project GLORIA (Global Observation Research Initiative in Alpine Environments, www.gloria.ac.at), in the year 2000 established four monitoring summits on the upper area of the Sierra Nevada massif (Target region: ES-SNE). The protocol involved the monitoring of the composition vascular plant species and soil temperatures with the study of lichens as an optional way not developed in depth (Pauli *et al.*, 2004). With the intention of suppling the lichen data gap, a new project was applied to the National Parks Network (Environmental Minister), it would be continued with the GLORIA methodology on the summits, extending the sampling surface up to eight summits (Target region: ES-SNN), and incorporating the detailed monitoring of lichens (Molero Mesa *et al.*, 2009). The project was conceded being the first time that lichens have been monitored with this aim in Sierra Nevada. Therefore, it has given us the possibility to compile valuable lichen records which might be used in the future for the study of processes in relation to global warming.

Concluding, the aim of this paper is to show the sampling results of monitoring in Sierra Nevada analysing the biodiversity of lichens, the altitudinal and horizontal gradients effects on species richness and also the correlation of lichens with the average soil temperatures available from GLORIA project.

2. Material and methods

2.1. Study Area

The study area is situated on the Sierra Nevada massif, southern part of Spain, inside the Baetic range where the highest peak on the Iberian Peninsula is reached (Mulhacén, 3481 m).

The GLORIA field manual (Pauli *et al.,* 2004) was followed to select and permanently mark eight sampling summits assembled in two target regions on this massif (Fig. 1). In the central-occidental zone of the range, with altitudes between 2668 m and 3227 m, was situated the ES-SNE target region: Machos (MAC) 3227 m; Tosal Cartujo (TCA) 3150 m; Cúpula (CUP) 2968 m and Pulpitito (PUL) 2778 m. The second target region (ES-SNN) was located

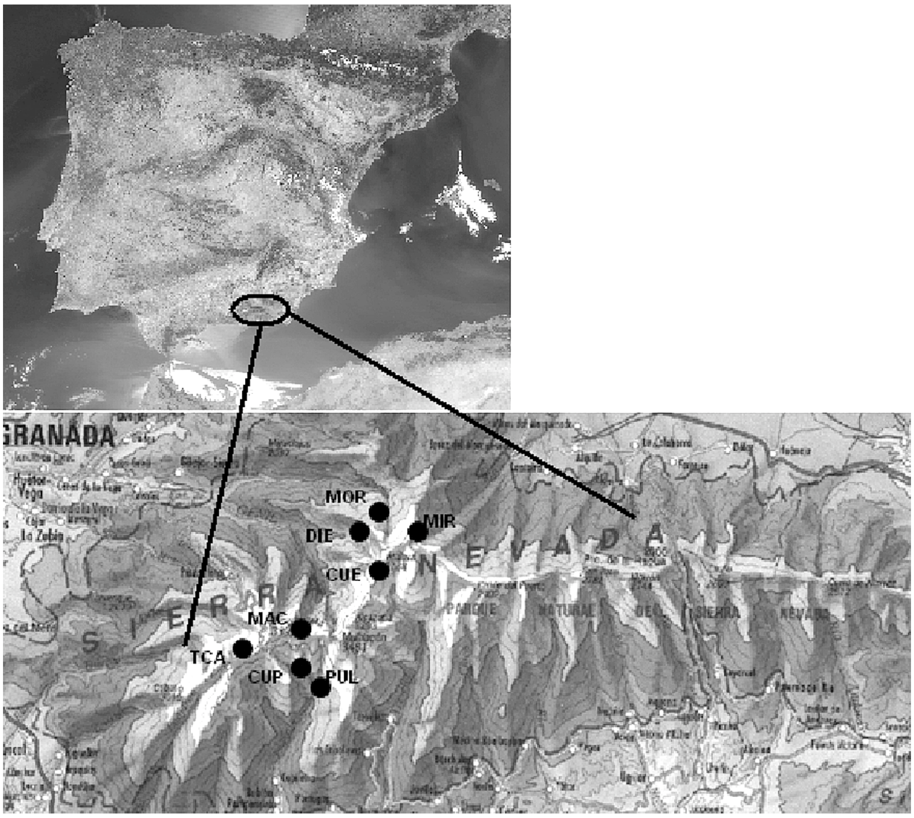

Figure 1. Location of sampling summits in Sierra Nevada.
Figura 1. Localización de las cimas de muestreo en Sierra Nevada.

on the oriental zone of the range: Cuervo (CUE) 3144 m; Diegisa (DIE) 2800 m; Mirón (MIR) 2760 m and Monte Rosa (MOR) 2668 m.

All the summits are exposed to the same local climate, Mediterranean bioclimate in its pluviseasonal oceanic variant (Rivas-Martínez *et al.*, 2007), with a pronounced summer drought at all altitudes and precipitation as snow almost exclusively above 2500 m during the winter season. They have also similar bedrock material, siliceous, and present low impact by land use (livestock).

The vegetation change from the lower summits (i.e. DIE or MOR), where shrub communities are important in the landscape, to the highest summits such us MAC, where the vegetation is constituted by psycroxerophitic grasses and scree plants less relevant at first glance.

2.2. Sampling designs

The sampling design follows the GLORIA field manual (Pauli *et al.*, 2004). Firstly, the survey area on each summit was defined as a polygon with four corners, at each point of the compass (N, S, E and W) and at an altitude difference of 5 m form the highest summit point (HSP) and a lower area extending from 5 vertical metres below summit to 10 vertical metres below

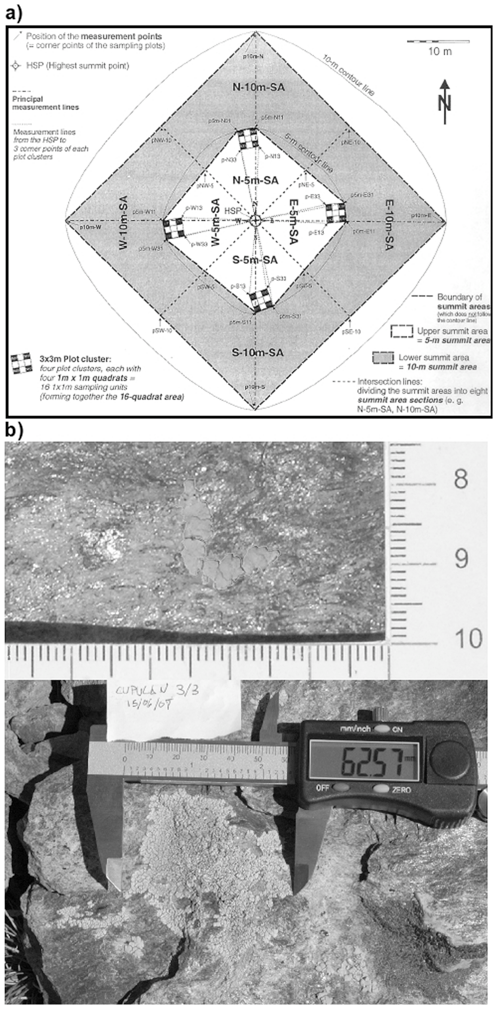

Figure 2. a) Scheme of the *Multi-Summit* sampling design; b) Lichenometry measurements Figure 3.
Figura 2. a) Esquema del diseño de muestreo, b) Medidas liquenométricas.

summit. Intersection lines from the HSP to the directions NE, SE, SW and NW resulted in eight summit area sections (SASs; four upper and four lower ones). Secondly, four quadrat clusters (3 m x 3 m resulting in nine 1 m^2 quadrats) were established on each cardinal direction (N, E, S, W) (Fig. 2a). The lichens sampling, floristic composition and lichenometry measurements, were recorded in the four corners quadrats of each 3 m x 3 m quadrat cluster (128-1 m^2 sampling quadrats), in the same place where other vascular plants measurements according to the GLORIA method were also recorded.

For the floristic data a protocol of determination derived from a phytosociological method (Roux, 1990) was followed: a visual inventory of the area was done to find the main taxa and later, with the help of a magnifying glass (15 x), a complete zig-zag lines crossed the quadrats to detect the lichens less apparent visually. With the intention of avoiding misidentifications with some problematic species, samples in neighbouring zones were taken to analyse later in the laboratory.

The lichenometry measurements were chosen as a method of monitoring the lichens at medium/long term (Palmqvist *et al.*, 2008). They were done on a selected quadrat (10 cm x 10 cm) inside each of the 1 m^2 quadrats. We superimposed a graduated square that allowed to quantify the area covered by the chosen lichen and take measurements of its diameter, coverage, etc (Fig. 2b). The goal of this process is to record a series of identifiable lichen on the scattered rocks in the soil sand, do a monitoring of its growth, trying to establish the relation between these data and the temperature data in the future.

The temperature data, one hour records, were taken by a data-logger (StowAway Tidbit) introduced at 10 cm below the surface, on each central quadrat (22) in the 3 m x 3 m quadrat cluster.

2.3. Data analysis

The identification and distribution of the lichen flora was done thanks to the usual reference books and especially Wirth (1980), Casares & Llimona (1982), Egea *et al.* (1982), Clauzade & Roux (1985), Wirth (1987), Casares & Llimona (1989), Purvis *et al.*, (1992) and Lhimona & Hladun (2001).

For the analysis of species biodiversity, the Shannon-Weaver index was used (Del Rio *et al.*, 2003).

The effect of exposure and altitude on lichen species richness values at 1 m^2 quadrats was tested by Analysis of Covariance (ANCOVA) with altitude as the covariate. Linear regression was used, on the one hand, to analyse the relationships between species richness, altitude and average soil temperature;

on the other hand, to explore the possibility of a relationship between species richness and Shannon-Weaver Index values from lichen with the same values as vascular plants. The temperature data corresponds to the period from October 2006 to September 2007, the first year after vegetation sampling on all of the summits. Both analyses were performed in the statistical package SPSS.

3. Results and discussion

The whole of lichens taxa recorded on the summits was 58 (Annexe 1), which mainly belong to the following families: *Lecanoraceae* (11), *Megasporaceae* (9), *Acarosporaceae* (7) and *Lecideaceae* (6) (Fig. 3).

The distribution of these taxa are mainly influenced by the type of substrata in the sampling quadrats, thus the majority of quadrats are situated on one of the common substrata in Sierra Nevada "canchal" (schist scree with different sizes), except MAC where the substrate is composed by big blocks of schist stone. This bedrock material is not alone in the substrate, other

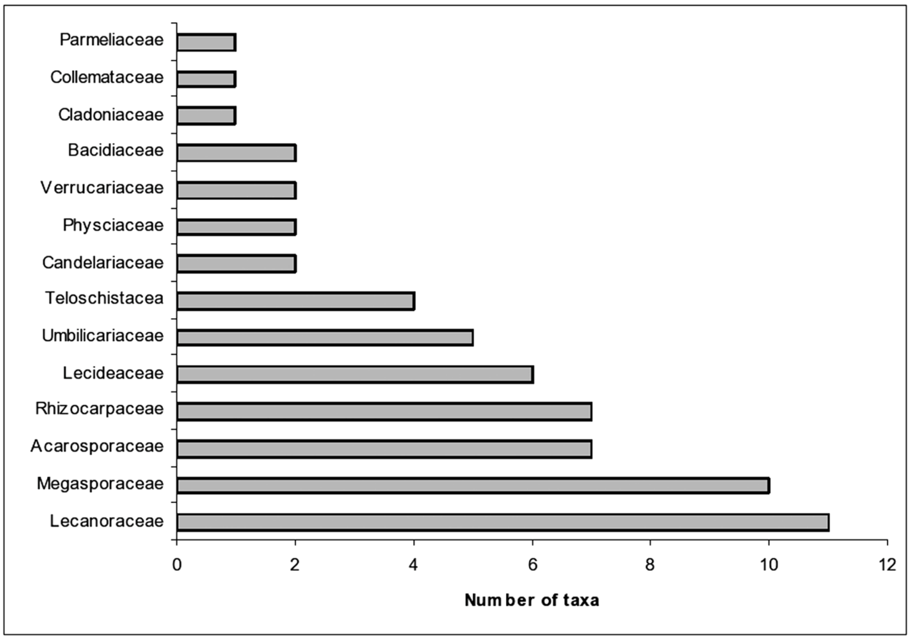

Figure 3. Taxonomic spectrum for the most relevant families in the sampling quadrats.
Figura 3. Espectro taxonómico de las familias más relevantes en los cuadrados de muestreo.

siliceous components as quartzite and siderite are mixed in with it. Schist stones happen on all of the summits except for PUL where a high level of carbonates has been detected.

The studied communities are composed of quionophilous and nitrophilous species due to the horizontal position and proximity to soil surface exposed to a long duration of snow coverage and a high degree of contact with the deposited detritus in the soil surface. The communities are dominated by three species very frequent in the massif: *Rhizoplaca melanophtalma*, *Lecanora polytropa* and *Lecidea atrobrunnea*, one of the lichens with wider presence in the rocks of the Sierra Nevada upper vegetation belt.

When the rock chunks are small and submitted to a certain movement, scree zones, the lichens are primary colonizers with scanty development and slightly apparent bodies. On the acid rocks, the most significant species are *Lecidea promiscua* and *Lecidea auriculata*, frequently accompanied by some yellow *Rhizocarpon* species. These communities can be included in the *Rizocarpion alpicolae* alliance Klement 1955, specifically in the *Rhizocarpetum alpicolae* association Frey 1922.

The areas with medium-large vertical blocks show a diverse flora with quionophilous lichens such as several species of *Umbilicaria*, *Lecanora rupicola*, *Sporastatia testudinea* or *Pleopsidium flavum*. Over carbonate substrates, the appearance of the lichen population is more varied than in the siliceous bedrock. Then, the communities are enriched with species such as *Lecanora muralis* or *Lecidella carpathica* and other less common like *Lecidella patavina*, *Sarcogyne privigna v. calcicola* or *Staurothele areolata*.

In the cracks of rocks appears *Collema crispum*, one of the few fruticulous lichen that we have sampled.

All these taxa are not distributed in the same way in the sampling summits. For example, *Lecidea promiscens*, *Lecanora polytropa* and *Lecidea atrobrunnea* are common to all of summits, emphasizing also the two last ones due to the fact that they are abundant in the Sierra Nevada massif. While, other taxa such as *Caloplaca arenaria*, *Candelariella vitellina*, *Lecanora muralis* ssp. *muralis*, *Lecanora polytropa* v. *alpigena*, *Lecidea auriculata* and *Rhizoplaca melanophtalma* are shared among seven summits. The opposite case, the presence of taxa only in one of the summits, i.e. *Caloplaca variabilis* var. *ocellulata* and *Staurothele areolata* which live in the PUL summit as consequence of the presence of basic substrates.

Focusing on the numerical data we could make some other comments. At first glance, we cannot observe a clear pattern between species richness and altitudinal gradient, at the total summit or exposure level (Table 1). In the same table we can also detect how the lowest majority values on species richness are distributed on the east side of five of the eight summits.

Table 1. Temperature measurements (yearly mean) on each summit and aspect.
Tabla 1. Medidas de temperatura (media anual) por cima y orientación.

Summit	Aspect	Tª	Summit	Aspect	Tª
MOR	N	5.53	**CUP**	N	4.55
	S	9.13		S	6.27
	E	6.26		E	5.91
	W	7.36		W	5.08
MIR	N	5.11	**CUE**	N	2.7
	S	6.57		S	4.83
	E	6.28		E	4.03
	W	5.02		W	2.49
PUL	N	6.25	**TCA**	N	2.69
	S	6.75		S	3.79
	E	5.94		E	4.53
	W	5.8		W	2.91
DIE	N	4.09	**MAC**	N	0,62
	S	5.64		S	2.81
	E	5.47		E	1.91
	W	5.96		W	1.02

To support these interpretations, we did a statistical analysis about the relationships between species richness at 1 m^2 quadrats and altitude, exposure and average soil temperature (Table 2). As a result, the relationships were not significant even though we studied the temperature series thoroughly looking for the influence of maximum or minimum temperature values on the lichens distribution. Again no prominent observations were found (Table 3).

The biodiversity was measured with the Shannon-Weber index (Table 4) finding its lowest values on the east side. The possible relationships with the homologous values on vascular plants were also explored but no significant connection was detected (Table 5).

Table 2. Number of taxa on the eight GLORIA summits. SR = Species richness; N = north; S = south, E = east; W = west.
Tabla 2. Número de taxa en las ocho cimas del proyecto GLORIA. SR = Riqueza de especies; N = norte, S = sur, E = este, W = oeste.

	MOR	MIR	PUL	DIE	CUP	CUE	TCA	MAC
Altitude (m a.s.l.)	2668	2717	2778	2800	2968	3144	3150	3327
Total SR per summit	18	28	20	16	14	17	12	30
SR- N	6	22	8	11	9	18	10	17
SR- S	8	13	12	7	10	12	4	20
SR- E	12	0	8	1	1	6	9	16
SR- W	12	11	10	13	6	12	7	8

Table 3. Results from One-Way ANCOVA and linear regressions for measures of species richness against the independent variables aspect, altitude and average soil temperature (2006-2007).
Tabla 3. Resultados de la ANCOVA de una vía y la regresión lineal para la riqueza de especies frente a las variables independientes orientación, altitud y temperatura media (2006-2007).

Species richness in	**1 m² quadrats**	
ANCOVAs		
Aspects	2.011	0.136
Altitude	2.279	0.143
Linear regressions		
Altitude	2.069	0.161
Average soil temperature	3.253	0.081

Table 4. Results of Shannon-Weber index on each aspect fot the eight summits.
Tabla 4. Resultados del Índice de Shannon-Weber para cada orientación en las ocho cimas.

	MOR	**MIR**	**PUL**	**DIE**	**CUP**	**CUE**	**TCA**	**MAC**
N	2.522	4.176	2.914	3.293	3.171	3.631	3.143	1.865
S	2.725	3.114	3.273	2.664	1.807	3.486	1.895	2.242
E	3.403	0	1	0	0	2.355	2.948	2.319
w	3.441	2.695	3.059	3.558	2.631	3.341	2.565	2.096

Table 5. Results from linear regression for measures of Lichen species richness/Lichen Shannon-Weaver Index against plant species richness/Plant Shannon-Weaver Index.
Table 5. Resultados de la regresión lineal para los datos sobre Riqueza de especies liquénicas/Índice Shannon Weaver en líquenes frente a Riqueza de plantas vasculares/Índice Shannon-Weaver en plantas vasculares.

Linear regressions		
Lichen species richness in	**1 m² quadrats**	
	F	**P**
Plant species richness	3.017	0.093
Plant Shannon-Weaver Index	3.130	0.087
Lichen Shannon-Weaver Index in	**1 m² quadrats**	
Plant species richness	0.034	0.854
Plant Shannon-Weaver Index	0.117	0.735

Finally, the lichenometry measurements were recorded on 13 taxa, (i.e. Table 6 measurementsin TCA-E) *Aspicilia cinerea, Caloplaca arenaria, Candelariella aurella, Lecanora muralis, Lecanora polytropa, Lecanora polytropa var alpigena, Lecidea atrobunnea, Lecidea auriculata, Lecidea promiscens, Rhizocarpon*

Table 6. Example of lichenometry measurements in TCA summit.
Tabla 6. Ejemplo de medidas liquenométricas en la cima TCA.

	Aspect	Quadrat	Specie	Area (mm^2)	Length (mm)
TCA	E	11	*Lecidea atrobunnea*	169.9514	96.3755
		13	*Lecidea atrobunnea*	99.5899	94.8613
		33	*Lecidea auriculata*	160.2323	138.9505
		31	*Lecanora polytropa*	59.4779	72.0432

geographicum, Rhizoplaca melanophtalma and Xanthoria elegans, with the intention of using them in the future to evaluate their growth and to verify if relation exists between the speed of growth, the orientation and the temperature data.

The evidence that lichens are greatly affected by environmental disturbance of human origin, significantly by global warming effects, make this kind of detailed monitoring program even more necessary which will help us to conserve the biodiversity and to understand more about the lichens ecology.

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