VEGETATION AT VENTISQUERO DE LA CONDESA (SIERRA DE GUADARRAMA, MADRID) AND ITS THERMAL-NIVAL DETERMINANTS

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I. INTRODUCTION

The study analyzes plant distribution incidence at a snowpatch at Ventisquero de la Condesa, in Sierra de Guadarrama (Madrid, España). This curved nival hallow area faces SE and is located between elevations of 2180-2210 m, a few meters below the summit region of Alto de las Guarramillas (40º 47' 10'' N and 3º 58' 35'' W, 2258 m) (Figs. 1, 2 and 3). The hallow is 625 m long and 85m wide and covers an area of approximately 5.3 hectares.

To determine plant distribution and analyze the extent to which the vegetation is affected by snow cover duration and ground temperature, we established 29 cross sections located at right angles to the slope and spaced at 20 m intervals. Microplots measuring 0.25m^2 were spaced every 3 m in each cross section for a total of 579 plots. A complete plant inventory was made for each microplot and included species identification, the number of individuals and the coverage rate (Fig. 4).

Snow cover distribution at the nival hallow was monitored for the period 1996-2004, using digital oblique photographs that were georeferenced with a high resolution Digital Terrain Model. Once the statistical data was obtained, we created a map of the study area divided into sectors according to the average number of days snow cover for each sector.

To determine the real temperature at the nival hallow and to compare it to temperatures in adjacent areas, we established a network of automatic thermometers capable of storing hourly thermal readings for a full year (specifically October 1, 2004-September 30, 2005). The first thermometer designated «AIR», recorded temperatures on the summit of Alto de las Guarramillas at 2258 m. Two ground thermometers were placed in the next sector at 2248 m; the «SUMMIT SURFACE» thermometer was installed at a depth of 10 cm while the «SUMMIT DEEP» one was at 60 cm. This sector is a very windswept area and average yearly snow cover is low.

The vegetation typical of this summit area is psychro xerophile grassland. A third ground thermometer, «SURFACE BRUSHWOOD» was located at 2223 m and at a depth of 10 cm in an area populated with dense thickets of brushwood (*Cytisus carpetanus*), near the upper edge of the nival hallow. The longest average annual snow cover occurs in the center of the nival hallow at 2205 m. Two thermometers were installed in this area: one designated «SURFACE SNOW» was placed at a depth of 10 cm while the «DEEP SNOW» one was at 60 cm. The last thermometer, «DEEP PRONIVAL», was installed at 2187 m and buried to 80 cm, at the lower edge of the nival hallow in a pronival zone covered by dense hygrophila grassland.

II. RESULTS

The surface of Ventisquero de la Condesa is colonized by 29 species of small, short-stemmed plants that form a patchy ground cover at the end of the summer and have an average coverage rate of 32.59%. Only two of the species are cryptogams (a fern and a moss), while the remaining 26 phanerogams correspond to 11 families: *Campanulaceae, Cariofilaceae, Compositae, Crasulaceae, Cruciferae, Escrofulariaceae, Gentianaceae, Gramineae, Leguminosae, Cupresaceae y Poligonaceae* (Table 1). The most widely found species in the area are the grasses *Agrostis truncatula*- and a polygonaceae -*Rumex acetosella*-, that occur in 59.75% and 44.37% of the plots, respectively. Other grasses are also frequent and include -*Koeleria caudata* (37.61%) and *Avenella iberica* (30.50%)-, two composites -*Leucantempsis pallida* (31.37%) and *Senecio pyrenaicus* (25.30%)-, a caryophyllacea -*Paronychia polygonifolia* (29,21%) -, a crassulacea -*Sedum candolei* (20,44%)- and the moss, *Politrichium juniperinum* (21.83%). At the other end of the spectrum with < 2% occurrence in the plant inventories are *Juniperus alpina*, *Gentiana lutea*, *Campanula herminii, Cerastium ramosissimum, Silene ciliata, Deschampsia felexuosa* and *Jurinea humilis*.

In terms of abundance or the number of plants per surface unit (plots of 0.25 m^2), the most frequent are the three grasses -*Koeleria caudata, Agrostis truncatula* and *Avenella iberica*- with an average of 5.40, 4.38 and 4.25 individuals/plot, respectively. The next abundant are the polygonaceae *Rumex acetosella* (4.19 inds./plot) and the crassulacea *Sedum brevifolium* (3.54 indvs./plot) and *Sedum candolei* (3.03 indvs./plot). The remaining species register averages of <1 ind./plot , except for *Politrychium juniperinum* and *Leucantemopsis pallida*.

Monitoring of the site was accomplished using surface photography from 1996-2004, and the results showed that the average snow cover duration within the boundaries of Ventisquero de la Condesa was 209 days (Fig. 5). This overall statistical value, however, is the average of some appreciably different individual values: for 23.5% of the surface area, snow cover is moderate (180-200 days); 44.3%, moderately high (200-220 days); 23.2%, high (220-240 days); and only 9%, very high (240-250 days) (Fig. 6).

At the nival hallow, snow cover duration is related largely to distance from the summit area (correlation coefficient 0.747) and to a lesser degree, to the proximity to the center of the nival hallow (correlation coefficient 0.433). In contrast, snow cover duration appears to have only a slight relation to the rockiness or instability of the surface (correlation coefficient -0.004 and -0.047, respectively.). This would indicate that regardless of the surface features, snow cover duration increases inversely to elevation and to distance from the central zone. The E-SE orientation tends to favor snow accumulation and permanence more than the S-SE direction.

The results from thermal monitoring show contrasts between the areas in and outside the nival hallow (Table 2). The most extreme thermal readings are associated with the AIR thermometer (Fig. 7) that recorded air temperature. Values ranged from a low -16.68º C to 46.75º C, and 100 freeze/thaw cycles in a year. For ground temperatures, the most divergent set of values was for the SUMMIT SURFACE thermometer (Fig. 8), with an absolute minimum of -7.42º C and a maximum of 29.43º C, and 19 freeze/thaw cycles. A comparison of the readings for this thermometer and the thickness of the snow cover, reveals that when snow thickness is >20 cm, ground temperature stabilizes from 0.5º C to -0.5º C, regardless of whether the air temperature is much higher or lower. When snow cover is thinner, the ground tends to loose heat throughout the winter and remains frozen for a long period (51 days). This explains why there are more freeze/thaw cycles at the end of autumn and the beginning of spring. The data for the SUMMIT DEEP thermometer shows an expectedly narrower range of temperatures (21.16º C) with an absolute minimum temperature of -4.44º C, which indicates that the ground freezes slowly through the winter until it reaches 0º C very late in the season. It remains frozen for 105 consecutive days, after which is slowly begins to thaw to the beginning of spring. The reduced number of freeze/thaw cycles (only 7) is attributed to the fact that the cycles occur shortly before or after the prolonged period when the ground is frozen and temperatures vary <0.5º C

The data derived from the thermometers located in the center of the nival hallow are very different that those installed at the summit area. Although the SURFACE SNOW thermometer recorded a high of 22.39º C for daytime in the summer, and basically coincided with those of the ground thermometers previously cited (Fig. 9), what is different is that when snow thickness exceeds 20 cm, the snow surface temperature stabilizes at about 0.5ª C. This occurs in the autumn and thereafter, the temperature drops so slowly that even by late spring it does not go below 0º C. For this reason, the absolute minimum is only -0.08º C and occurs in May. When the snow disappears at the beginning of June, the temperature rises sharply as it does at the SUMMIT SURFACE site. In the SNOW SURFACE area there are just two freeze/thaw cycles, and the ground is frozen for only 32 days. The DEEP SNOW thermometer displays exactly the same tendency, but with a lower range in temperatures.

The data from the SNOW SURFACE and BRUSHWOOD SURFACE are analogous except that the period of thermal stability at the SNOW SURFACE site is shorter, since the snow cover duration is also shorter (Fig. 10). The same similarity of results holds true for the DEEP SNOW and DEEP PRONIVAL thermometers: the latter was installed at a greater depth (-80 cm) where ground temperature never exceeds 0º C (Fig 11).

To determine the effect of snow on the distribution and presence of plant species at the nival hallow, we grouped the 579 inventoried plots, keeping in mind their locations, according to the four areas we had established for snow duration. As a result, 126 (21.8%) of them were located in the moderate snow duration zone, 256 (44.2%) in the moderately high area, 144 (24.9%) in the high area, and 53 (9.1%) in the very high area. Next, we determined the percentage of the plots for each snow duration area where each of the 28 species recognized in the inventories where present, and we obtained the correlation coefficient between the percentages of each species present in each area and the respective average values for snow duration (Table 3).

This statistical analysis reveals that practically all of the species are compatible with all of the levels of average snow duration in the nival hallow area (180-260 days/yr) and highlights

that only 6 species show a positive correlation higher than 0.05 with the average snow duration values: *Rumex acetosella* (CC= 0.889), *Politrychium juniperinum* (CC= 0.768), *Linaria saxatilis* (CC= 0.747), *Koeleria caudata* (CC= 0.556), *Criptogama crispa* (CC= 0.555) and *Senecio pyrenaicus* (CC= 0.547). In comparison, 9 species have a negative correlation coefficient superior to -0.50: *Avenella iberica* (CC= -0.987), *Cytisus carpetanus* (CC= -0.951), *Leucantempsis pallida* (CC= -0.950), *Hieracium vahlii* (CC= -0.843), *Sedum brevifolium* (CC= -0.764), *Jurinea humilis* (CC= -0.747), *Digitalis thapsi* (CC= -0.698), *Festuca curvifolia* (CC= -0.698) y *Jasione crispa* (CC= -0.647). The correlation coefficients for the remaining 13 species have neither positive nor negative correlation coefficients that are significant, so they are considered unaffected by the longer or shorter duration of snow cover and more inlfuenced by the presence of other environmental factors such as rocky surfaces, instability, exposure, etc.

In general, abundance (number of individuals/surface unit) tends to diminish as snow cover duration lengthens, but this does not mean that there is marked decrease, since the margins of variation among the average values for abundance recorded in the four differentiated areas are narrow (26-34 individuals/plot) and their correlation coefficient in relation to average snow cover duration is 0.466.

CONCLUSIONS

Nearly all of the species present at the nival hallow are capable of enduring periods of snow cover such as those recorded during the study (180 -250/260 days/yr), but they may show differences in how well they adapt to variations in this environment. For example, more than half of the species are basically unaffected by these variations and distribute themselves all over the nival hallow area independently of the areas mapped for snow cover duration, while the other half shows appreciable levels of correlation. Depending on the case, this correlation can be positive or negative.

The plants that prefer snow tend to grow mainly in the area below the central sector of the nival hallow where topography, orientation and a leeward location favor snow accumulation and permanence. At the same time, while the density of some plant individuals increases as they penetrate these sectors, others may not increase and some may even diminish.

The plants that do not prefer snow tend to occupy the edges of the nival hallow and particularly, the high areas near the summits. These are windswept areas where snow is blown downslope and does not easily accumulate, and the species most often found there belong to psychro xerophile grassland. There is also a significant representation of legume shrubs which make up a good part of the high mountain bushwood found in Sierra de Guadarrama.

The results of recent studies indicate that from the mid-twentieth century to the present, the number and extension of nival hallows in Sierra de Guadarrama have radically diminished. Given this perspective, the results of this study at the Ventisquero de la Condesa show a floristic stock and current structure associated with a decaying nival area that is being invaded by the adjacent plant population that has adapted to environments with less snow and moisture, and more exposure to fluctuations in temperature. This invasion, explained by the shortened snow cover duration, is taking place in a top-down direction. The species participating in this are common to the psychro xerophile grassland, or to a lesser degree, to the bushwood areas that grow above the nival hallow.