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Influence of snow distribution in vegetation cover and geomorphologic activity: Manzanares Headvalley, Sierra de Guadarrama, Spain.

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This work analyzes the relationship between landforms and erosion, vegetal cover, and annual snow cover duration and distribution. The study site is located in the watersheds of two mountain streams, Condesa and Valdemartín, at the source of the Manzanares River in the Guadarrama Mountains of Spain's Central Range. The Condesa watershed is delimited by the following mountains: Maliciosa (2,227 m; 40º 46' 10" N; 3º 58' 00" W), which marks the southern boundary of the study site, Alto de las Guarramillas (2,258 m; 40º 47' 10" N; 3º 58' 35" W), and Cerro de Valdemartín (2,282 m; 40º 47' 40" N; 3º 57' 40" W). The Valdemartín watershed covers the area between Cerro de Valdemartín and Cabeza de Hierro Menor (2,373 m; 40º 47' 56" N ; 3º 56' 10" W). The lowest elevation (1,795 m) is at the junction of the two streams (40º 46' 32" N ; 3º 57' 15" W).

The first phase of the study focused on creating specific maps of the site's geomorphology, vegetal cover, and snow cover duration and distribution based on topographic maps from the Comunidad de Madrid (the regional government of the province of Madrid). Slope and orientation information were also derived from these maps for GIS input. The 13 units of the geomorphologic map focus primarily on the delimitation of snow formations, and were established according criteria proposed by Christiansen (1996; 1998). Special emphasis was placed on the degree of stability associated with slope processes, which was measured by monitoring the movement of painted boul-

ders, a technique developed in earlier studies (Rapp, 1960; Nyberg, 1991) and recently applied in the Guadarrama Mountains (Palacios and Garcia, 1997; Palacios et al., 2003; 2004).

A map of vegetal formations and facies was developed according to photographic interpretation of digital orthophotos and photograms, 1:18,000 scale (1998), and was used to locate and differentiate the plants. Results from two seasons of field work (September 2001 and 2002) also provided data on the exact delimitation of the formations and facies, their floristic composition and structure, and their phytostabilizing capacity. During this phase of the study 14 plant facies were established.

A methodology tested by Palacios and Garcia (1997) and Palacios et al. (2003; 2004) was used to produce the snow cover duration and distribution cartography. Oblique digital photographs were taken from key points in the study area at least once a month and weekly during the thaw season, for the periods 1996-1997 and 2003-2004. The photographs were then corrected and georeferenced over a Digital Elevation Model (DEM) within 5 m accuracy. Statistical post-processing of the data produced a map divided into 10 categories according to the average number of days of snow cover duration during the study period from $\leq$60 days/yr to $>$220 days/yr.

Topographic information was transferred to ArcGis software to produce a TIN that provided altitudes, slopes and orientations in raster format for statistical and spatial processing. The range of altitudes from 1795-2373 m was divided into 4 equal classes and 2 unequal classes for each extreme; the slope was measured in degrees and classified into 8 categories; and the orientations were distributed among 8 classes of 45º sexagesimals. The Spatial Analyst extension of ArcGis statistically related the distribution of landforms, scored in inverse order to their stability, and vegetal formations, scored in inverse order to their phytostabilizing capacity, to categories such as snow cover duration, altitude, slope and orientation.

The results confirmed that snow cover duration had a direct impact on geomorphologic activity (0.83 correlation coefficient). Other factors such as wind exposure (0.33), and altitude, slope and orientation (correlation coefficients $<$0.10) were less significant, although, it is clear that by directly affecting the snow cover duration, these factors also indirectly conditioned geomorphologic activity. In fact, when looking only at the snow formations (old and active snow niches, areas of marked nival mobility, and active and inactive pronival areas), we found that the effect of snow cover duration on geomorphologic activity was more evident (0.87), and that leeward winds also had a direct impact (0.67).

The key factors in the distribution of vegetal formations and their phytostabilizing capacity in the study area include the degree of protection from prevailing winds and

snow cover duration (0.77 and 0.55, respectively). In analyzing the areas with more open formations where 45% of the surface is covered by snow grasses, we found that the correlation coefficient between vegetation and snow cover duration increased to 0.92 and that the influence of shade and exposure to leeward winds is highly significant (0.88 and 0.70, respectively).

Finally, the relationship between the lack of phytostabilization and the level of activity caused by erosion processes produced a correlation coefficient of 0.65, which emphasizes the fact that instability curtails the development, density and depth of rooting. This relationship is particularly visible in areas that are considered purely nival.

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