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Water harvesting techniques based on terrain modification enhance vegetation survival in dryland restoration

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ABSTRACT

To successfully restore drylands, where the scarcity of water is one of the main limiting factors for plant survival, water inputs should be enhanced as much as possible. A specific type of water harvesting that concentrates runoff generated in bare areas upslope (runoff source areas) in a planting area downslope (runoff sink area) is an effective technique that, unlike traditional restoration, does not entail much over-cost. The objective of this study was to analyze the effectiveness of terrain modification techniques, aimed at water harvesting, on a degraded hillslope at a quarry restoration site in an arid area (Almeria, southeast Spain). Two different terrain modifications, to harvest surface runoff and increase soil water retention, were applied at two different hillslope sectors: a) micro-catchments were constructed on the upper section of the hillslope, where the slope gradient was high and b) narrow terracing was done in the middle part of the hillslope, which was characterized by moderate slope gradients. An additional sector, not subjected to terrain modification treatment, was used as a control, and was set in the lower part of the hillslope where the slope gradient was the lowest. A similar planting system was adopted for all experimental treatments; *planting* was done in 12 fertility island patches. Within each patch 12 different autochthonous plant species were planted in a staggered pattern with 80 cm separation. All plant species, which were from a nursery, were planted within a 1 L container made from organic fibers and containing compost from plant residues enriched with zeolites. To determine the microtopographical modifications required in the analysis of the optimal water harvesting strategy, a digital elevation model, with 0.2 m spatial resolution, was created from the data generated using a terrestrial laser scanner. Runoff flow direction and contribution areas, as well as a set of topographical attributes strongly related to the terrain water retention capacity (wetness index, slope gradient, aspect, USLE LSF factor, etc.), were calculated. Results indicated that micro-catchments had the highest plant survival rates and vegetation coverage values because they were the terrain treatment areas with the largest capacity to retain run-on from contributing areas. The areas without terrain modification (control areas) showed the highest plant mortality.

1. Introduction

Continuous population growth and economic development increases demand for natural resources, which, in many parts of the world, are pushed to their natural limits. Moreover, there has been a shift from traditional exploitation patterns to more intensive ones, which endanger the viability and sustainable development of our society, along with the preservation of a healthy environment (Parry et al., 2004). Drylands, where water and nutrient scarcity limit natural ecosystem recovery, are particularly sensitive to human pressure, and their degradation threatens the livelihood of 2 billion people (Millenium Ecosystem Assessment, 2005). Thus, restoration practices aimed to reduce drylands degradation are crucial (Aronson et al., 2007). However, our ability to recover these systems is limited and restoration success rates are low (Carrick and Kruger, 2007; Valladares and Gianoli, 2007; Hardegree et al., 2011), especially in areas where the original vegetation assemblages have disappeared and natural soils have been completely removed (Bainbridge, 2007). This is the case for

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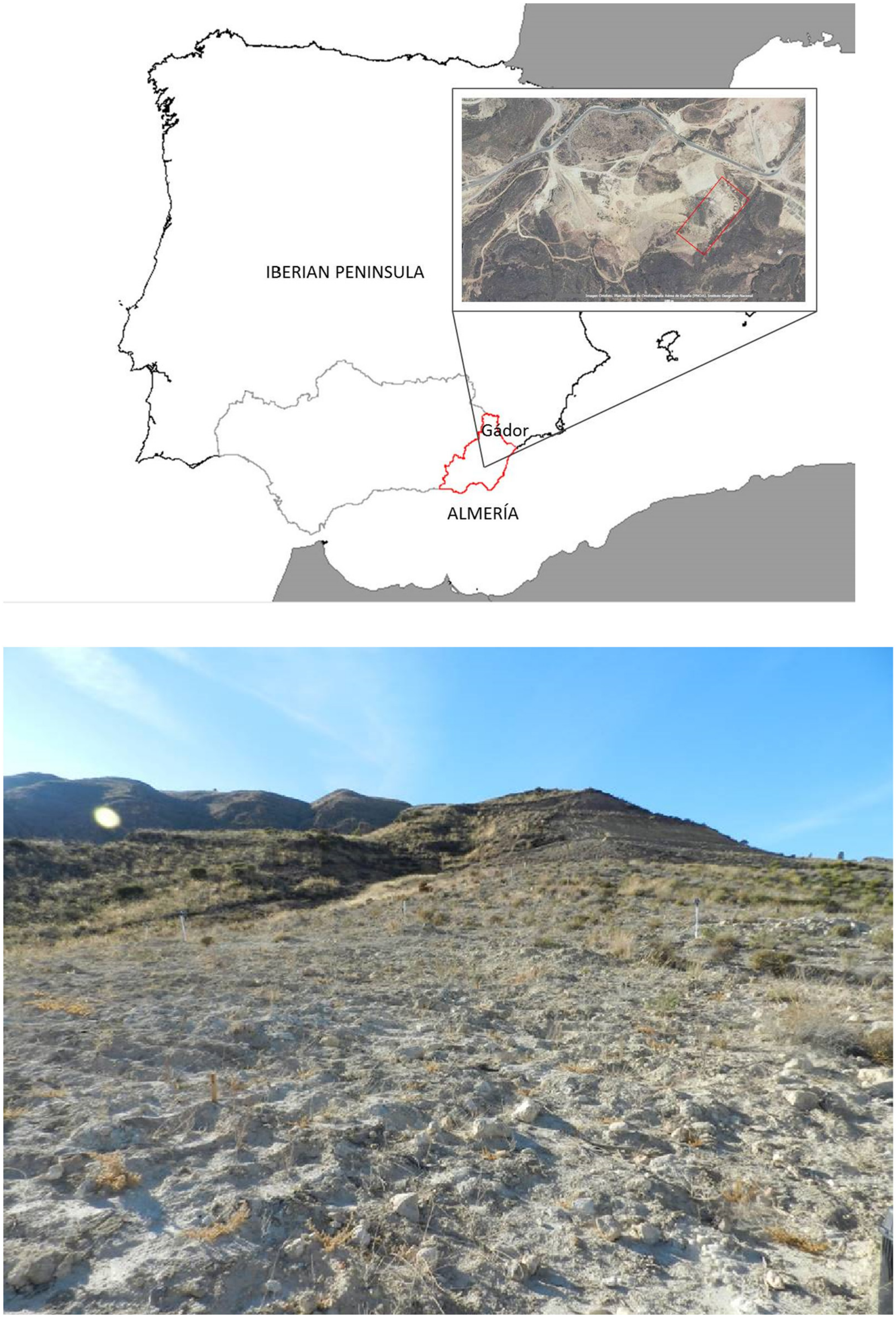

a

b

Fig. 1. Location of the study area in Almeria province (satellite view), Fig. 1a, and detail of the restored hillslope, Fig. 1b.

areas subjected to open-pit mining or quarrying, where the thresholds for natural restoration have been overpassed. Under these conditions, reclamation must begin with an easily erodible and low permeable mineral substrate over steep slopes (Luna et al., 2016). This fact, combined with aridity and low water retention capacity, increases vegetation water stress and hinders restoration success (Zancada et al., 2004).

The limited number of restoration examples on calcareous quarries in drylands have focused on: 1) rehabilitating the substrates (Moreno-Peñaranda et al., 2004; Maisto et al., 2010; Cook et al., 2011; Hueso-González et al., 2015); 2) reducing water stress of vegetation by means of water supply (Jorba and Vallejo, 2008; Sánchez et al., 2004); and 3) applying treatments that reduce both soil evaporation (Woods et al., 2012; Benigno et al., 2013; Wang et al., 2009; Li, 2002) and soil erosion by water (Smets et al., 2008; Luna et al., 2016), and increase water capture (Estrela et al., 2009). However, most of these treatments are