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Abstract: Drylands functioning depends on water fluxes and the retention of resources. The restoration of degraded areas should mimic the natural arrangement of vegetation in the landscape in a source-sink pattern. Reintroducing key woody seedlings through planting is a major concern in ecological restoration as these areas use to be overpassed degradation thresholds and ecosystem functions are limited. However, it is not clear how natural fluxes might determine seedlings performance of key shrub species. We have analyzed the microcatchment surface area of planting spots with and without water optimization treatment (waterproof surfaces with dry wells) and the survival and growth of Olea europaea seedlings during six years after planting in a semiarid degraded landscape. We recorded a positive effect of water optimization treatment in seedling survival and growth highlighting water limitation of these sites. We did not observe a clear and linear relationship between microcatchment collecting surface area and plant performance. The higher the collecting surface the lower the retention capacity of the planting pitch suggesting a loss of the integrity of the planting hole structure. Water optimization treatments were especially effective when collecting surface areas were low. These results might be useful for designing precision restoration actions in degraded landscapes.

Dear Editor,

The manuscript we are submitting to be considered for publication in the Special Issue *Ecodesert* analyses the occurrence of surface water fluxes in degraded dryland slopes and how ecological restoration actions should be adjusted to them in order to increase success. The sink-source pattern controls ecosystem functioning in these drylands and landscape restoration should study and interpret how resources are naturally redistributed to optimize land management. We both analyzed the relationship of the microcatchment area and artificial field water harvesting techniques with the survival and growth of *Olea europaea* planted seedlings.

We consider that the reported information might be relevant to actions involved in the reintroduction of lost key species in degraded dryland slopes both by identifying suitable planting sites and by selecting ecotechnologies to be site-specific implemented. Our study provides evidences and arguments to implement precision restoration in these patchy organized degraded ecosystems.

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How far surface water fluxes determine restoration success in Mediterranean degraded areas? Implications for dryland precision restoration

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ABSTRACT

Drylands functioning depends on water fluxes and the retention of resources. The restoration of degraded areas should mimic the natural arrangement of vegetation in the landscape in a source-sink pattern. Reintroducing key woody seedlings through planting is a major concern in ecological restoration as these areas use to be overpassed degradation thresholds and ecosystem functions are limited. However, it is not clear how natural fluxes might determine seedlings performance of key shrub species. We have analyzed the microcatchment surface area of planting spots with and without water optimization treatment (waterproof surfaces with dry wells) and the survival and growth of *Olea europaea* seedlings during six years after planting in a semiarid degraded landscape. We recorded a positive effect of water optimization treatment in seedling survival and growth highlighting water limitation of these sites. We did not observe a clear and linear relationship between microcatchment collecting surface area and plant performance. The higher the collecting surface the lower the retention capacity of the planting pitch suggesting a loss of the integrity of the planting hole structure. Water optimization treatments were especially effective when collecting surface areas were low. These results might be useful for designing precision restoration actions in degraded landscapes.

Keywords: *Olea europaea*, planting holes, seedling survival, source-sink pattern, water collecting surface area

1. INTRODUCTION

Vegetation in drylands is typically spatially distributed in patches within a matrix of exposed mineral soil which determines the structural and functional connectivity both at the slope and landscape scale (Okin *et al.*, 2015; Tormo *et al.*, 2020). Connectivity determines the capacity of materials to be redistributed along the slope and, eventually, exported off-site with potential harmful consequences of silting and floods. Therefore, when either total vegetation cover or vegetated patches decrease there is a global loss but a local increase of resources in sink areas which might be (micro)topography- or plant-driven patches (Mayor *et al.*, 2019). Connectivity and, hence, the spatial distribution of vegetation patches, strongly determine the movement of water in drylands, being water simultaneously a resource and a medium of transport of soil particles, propagules and nutrients (Bautista *et al.*, 2007; Okin *et al.*, 2018). At the stand scale, short distance movements of water, lower than 10 m, usually begin soon after the rain event started while losses of water towards first order channels need the combination of higher intensity rain events and certain moisture content of the uppermost soil profile (Puigdefábregas, 2005). Soil surface features, such as the cover of biological crusts, modulate runoff coefficients and, as a consequence, rain event characteristics needed to produce surface water fluxes (Lázaro *et al.*, 2015). The size and arrangement of vegetation patches finally determine the degree of integrity or degradation of the site as these patterns might be seen as indicators of degradation (Kéfi *et al.*, 2007), showing a negative dynamics as the connectivity of bare soil areas tend to increase with time while plant establishment decreases (Mayor *et al.*, 2013). The higher the degradation of an ecosystem, the lower its efficiency in retaining resources and the higher its vulnerability to further stresses. Puigdefabregas *et al.* (1999) defined the sink spots and their contributed drainage area as the functional units of drylands. It has been observed that artificial sink areas, such as planting holes, retain resources being the conservation of resources more effectively in landscapes with higher than with lower connectivity (Fuentes *et al.*, 2017). Consequently, planting holes and their collecting upslope surface area might be considered as the functional units in restored semiarid slopes. Microtopography is the ultimate feature of the slope which drives surface water movement.

Although there exist important spatial differences, in the period 1975-2015 the Mediterranean region experienced non-uniform increases in the daily concentration of the rainfall events as well as in the intra-event variability of rainfall behavior (Mathbout *et al.*, 2020). IPCC reports foresee a decrease in average precipitation at the end of the current century in the Mediterranean Basin, especially in its Western part, as well as higher probability of extreme precipitation events (IPCC, 2014). Under these scenarios, the pattern and behavior of surface water fluxes become even more relevant indicators for dryland ecosystem functioning.

Ecological functioning of drylands is controlled both by abiotic, mainly rainfall regime, and biotic drivers, from microbiota to grazing animals (Maestre *et al.*, 2016), and the retention and optimization of water inputs is essential to maintain active these biotic-driven processes. Planting seedlings of tree and shrub species is one of the most used actions in the restoration of degraded lands (Pausas *et al.*, 2004). Planting techniques aim at increasing water capture and retention to allow rapid growth of seedling roots to explore as much soil as possible to exploit its resources and to reach deeper soil horizons with higher water content (Padilla & Pugnaire, 2007). For this reason, in water-limited environments, the length of the first drought period after planting is the most critical stage determining restoration success (Vallejo *et al.*, 2006). Therefore, the longer the planting holes act as effective sink areas, the higher the probability of seedling survival and performance which is especially important in early post-planting stages.

More recently, alternative field planting techniques have been developed and tested to improve water availability to planted seedlings without involving external inputs of water. Mulches, microcatchments and, especially, preferential vertical water paths (dry wells) have shown positive results in the restoration of degraded Mediterranean drylands (Fuentes *et al.*, 2017; Valdecantos *et al.*, 2014). These and other ecotechnologies (Piñeiro *et al.*, 2013) are needed to increase restoration success especially when the site went beyond degradation thresholds and the reintroduction of the biotic component is not enough to recover ecosystem functions (Whisenant 1999).

The use of unmanned aerial vehicles (UAV) in the assessment and monitoring of different properties of ecosystems is increasing day by day (Gillan *et al.*, 2020). For instance, digital elevation models determining microtopography accurately have been used to study the recovery of peatland species (Harris & Baird, 2019), while LiDAR images are being applied to assess large scale restoration projects (Reis *et al.*, 2019). UAV are also used to assess restoration success of meadows (Davis *et al.*, 2020), bogs (Knoth *et al.*, 2013), or degraded drylands (Pérez *et al.*, 2019) but, as far as we know, they have not been implemented in the analysis of water fluxes and the performance of planted seedlings.

The main objectives of this paper are i) to identify surface water fluxes in a restored slope, ii) to relate the size of the collecting area in the planting holes with their sink capacity, and iii) to assess eventual relationships between seedling performance and collecting surface depending on the planting technique implemented. We hypothesized that the survival and growth of seedlings planted in semiarid slopes are strongly correlated to the size of the microcatchment of the planting hole, and that these relationships might fade when effective planting techniques aimed at water collection are applied.

2. MATERIALS AND METHODS

2.1 Study site

The study area is settled in the municipality of Albatera (coordinates 38°13’56.1’’N, 0° 56’37.3’’ W) in SE Spain, one of the most affected areas by runoff, soil erosion, degradation and, finally, desertification in Europe (Cantón *et al.*, 2011; Oñate and Peco, 2005). Mean annual precipitation and temperature are 267mm and 18.4◦C (AEMET opendata; Table 1), defining a semiarid thermo-mediterranean climate (Rivas-Martínez 1987). The sandy-loam-textured soils correspond to *Calcaric Regosol* (IUSS Working Group WRB 2006). Vegetal cover is scarce and sparse due to intense past land use, with large parts of unprotected bare soil. Several reforestation attempts occurred in the area in the last decades, especially pine plantations, which, in general, released poor success (Vilagrosa *et al.*, 2008).

2.2 Restoration actions

In February 2010, we established a planting trial in the area covering ca. 3 ha to confirm or not the effectiveness of microcatchments with dry wells as preferential vertical water paths, which previously offered very positive results in the establishment of *Olea europaea* seedlings (Valdecantos *et al.*, 2014). Passive improved water availability treatment (W1) consisted in 40x40x40 cm planting holes with two lateral 1-m channels, a 0.30 m^2 waterproof surface upslope the planting hole and a 5x20x20 cm (width, length and depth) trench filled with gravels (dry well) implemented in the proximity of the planted seedling. Control holes (W0) were 40x40x40 cm planting benches. Treatments were interspersed along the planting site. Seedling survival and basal diameter of all alive seedlings were recorded in April (initial data) and July 2010, February and July 2011, March 2012, January 2013 and April 2016, corresponding to 2, 5, 12, 17, 25, 35 and 74 months after planting. We calculated in all sampling dates basal area (BA) values in all combination of water availability treatment and class of individual catchment area (see below) by summing cross-sectional areas of all alive seedlings as follows

$$BA = \frac{\Sigma \pi di^2}{4}$$

where d_i corresponds to the basal diameter of each individual seedling.

Table 1. Annual mean precipitation and temperature for the 30-year historical series and the period 2010-2016 in three different periods: January to May, June to August and September to December. For each period, the number of days with a rainfall higher than 8 mm is included. Source of data: own data for the period 2010-2012 and Elche-Airport AEMET meteorological station (38°17'N, 0°33'W) for 2013-2016 and the long series.

	Period		*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*1990-2019*
Pp (mm)	Jan-May		145.0	103.2	66.0	96.3	13.9	46.4	54.9	113.7
		pp>8mm†	5	3	2	5	0	2	2	
	Jun-Aug		78.2	18.4	2.3	32.1	6.3	6.8	0.9	20.3
		pp>8mm†	2	0	0	1	0	0	0	
	Sept-Dec		82.1	100.6	133.0	36.7	102.6	159.4	65.0	132.9
		pp>8mm†	4	6	5	2	5	6	3	
	Total		**305.3**	**222.2**	**201.3**	**165.1**	**122,8**	**212.6**	**120.8**	**266.9**
Temp(°C)	Jan-May		13.4	14.7	14.1	14.2	15.9	15.3	15.7	14.7
	Jun-Aug		24.7	24.8	25.9	24.1	25.6	27.1	25.6	25.1
	Sept-Dec		16.5	18.1	17.4	17.7	19.0	18.4	19.6	17.9

† 8 mm is the established threshold for runoff production from natural precipitations in the experimental site (Valdecantos *et al.*, 2014).

2.3 Spatial analysis

In February 2018, we georeferenced a total of 267 planting spots by means of a Leyca GPS 1200 equipment. Coordinates of 15 high-quality ground control points were also taken to generate precise geospatial products during the image post-processing steps.

On 12 March 2018, we took a photogrammetric flight with an UAV equipped with a high quality RGB sensor (1 inch), with a mechanical shutter and high resolution camera (20 MP). The autonomous mission took place at constant altitude of 30 m over the ground and we used 85% forward overlap, and 65% side overlap, resulting in 485 pictures combining zenith and oblique angles.

Agisoft Photoscan software was used to obtain a high resolution orthophoto (8.6 mm per pixel) and a digital surface model (DSM, 1.72 cm per pixel). From these data, we classified the planting holes according to their average slope and aspect.

Through the Arc Hydro Tools module of ArcGis, we studied the flow movements in the study area. After filling the DSM sinks, the flow direction and accumulation maps were calculated to see how the water flows concentrate and check eventual relationships with plant survival and performance. The maximum flow accumulation can be understood as the number of cells draining upstream a given pixel. The current pixel size in the field is the GSD (Ground Sample Distance) so, after transformation, this value represents the catchment surface that would feed a given point after a rain event producing runoff. In the center of each planting hole, we established a circular buffer of 0.5 m of radius encompassing the planting hole and its surroundings. Then, we intersected the created drainage network (flow accumulation) and the buffered planting holes, assigning to each hole the maximum value of the drainage cells that passed through its area of influence.

We assessed the functionality of the planting holes as the remaining capacity to capture and collect rainfall water on its surface. This sink capacity was established by the GIS software that considers a sink the pixel or a set of pixels whose flow direction cannot be assigned to any other surrounding pixel. It has been well established that these sink areas in drylands can become resource islands on all hierarchical scales from the plant to the basin (Mayor *et al.*, 2011)

2.4 Data analysis

Statistical differences of seedling survival between classes of microcatchment area and water availability treatment, at five and two levels respectively, were assessed in all sampling dates by log-linear analysis. Basal diameter growths between each sampling data and the initial diameter values and the sink volume eight years after planting were assessed by two-way ANOVAS after checking normality and homogeneity of variances. In case of significant differences in the factor classes of microcatchment area, Duncan’s post-hoc tests were performed. All analyses were conducted with SPSS v15.0 for Windows.

3. RESULTS

Planting spots were mainly established in hillsides with steep slopes with an average of 21° (equivalent to 38,4% slope) and S-SW exposure ranging from 90˚ to 310˚, irrespective of the water availability treatment (Fig. 1).

The intersection of the drainage network (flow accumulation) and the buffered planting holes resulted in five different classes of collecting area depending on the upstream surface that contributes water to that drainage segment. The contribution surface of the established classes assumed average values between 0.6 m^2 and 70 m^2 (Table 2).

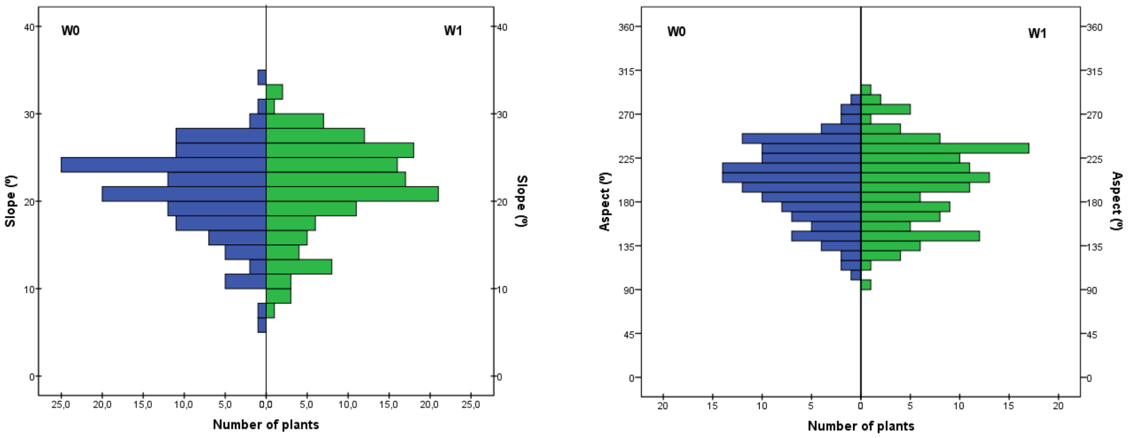

Figure 1. Frequency of planting holes according to their average slope (left) and aspect (right) within the experimental plot. For each figure, W1 and W0 correspond with the passive improved water availability and control treatments, respectively.

Table 2. Classes of individual catchment area depending on the upstream surface area that contributes water to the planting hole and number of plants in each combination of treatment and class. Values of Average catchment area correspond to mean and standard errors. W1 and W0 correspond with the passive improved water availability and control treatments, respectively.

CLASS	*Range of catchment area (m^2)*	*Average catchment area (m^2)*	*Number of plants*	
			W0	*W1*
1	< 1.2	0.7 ± 0.0	28	26
2	1.2 - 4.5	2.5 ± 0.1	23	30
3	4.5 - 9.6	6.7 ± 0.2	30	23
4	9.6 - 21.5	14.0 ± 0.5	23	31
5	>21.5	70.9 ± 14.6	27	26

At planting, soil treatments provided 0.50 m^2 of surface area in the planting holes with a potential sink volume of 8.91 and 12.96 L for W0 and W1 treatments, respectively (data not shown). Eight years after planting, the size of the upstream individual catchment area had a negative effect over this volume (F=2.75, p=0.029) regardless of the treatment applied (F=0.809, p=0.369). The smallest class of catchment area showed the highest values of sink volume in the surface of the planting hole (Fig. 2). However, these values of sink capacity were extremely reduced from the initial conditions soon after planting.

Early seedling survival was very high in both water availability treatments and all five classes of collecting surface. The lowest survivorship two years after planting did not go below 90% under any experimental situation. However, in March 2012, twenty-five months after planting, we observed marginal statistical differences ($\chi 2$=8.134, p=0.087) according to the collecting class of the planting hole, with Class 4 showing the lowest seedling survival (92.4%). In the final sampling date, survival was highly affected by the extreme drought of 2014 and 2016 when precipitation records were around 45% of the average year (Table 1). Overall seedling survival fell to 58.5% with a significant positive effect of the implementation of the dry well in the planting hole ($\chi 2=4.017$, $p=0.045$) that reached an absolute 12% higher survival than control seedlings. Dry wells improved seedling survival with time (Fig. 1) as precipitation amount and/or distribution of precipitation events were quite favorable to avoid excessive water stress to plants (Table 1). We did not observe significant differences of survival between classes of microcatchment surface area but there was a trend to a higher effectiveness of the dry wells in holes with low collecting areas (classes 1 and 2). This positive trend effect of the dry well decreases as the collecting surface increases and it even turned negative in surface areas above 9.6 m^2 (Fig. 3).

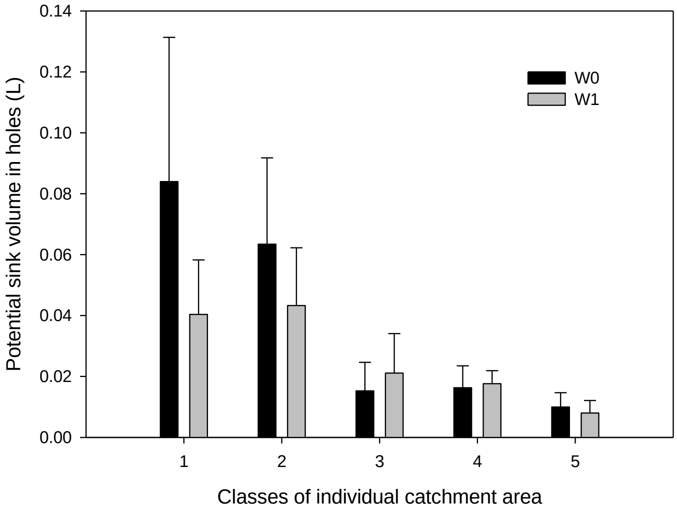

Figure 2. Potential sink volume (L) in holes eight years after site preparation in the five classes of individual catchment areas and water availability treatments. W1 and W0 correspond with the passive improved water availability and control treatments, respectively.

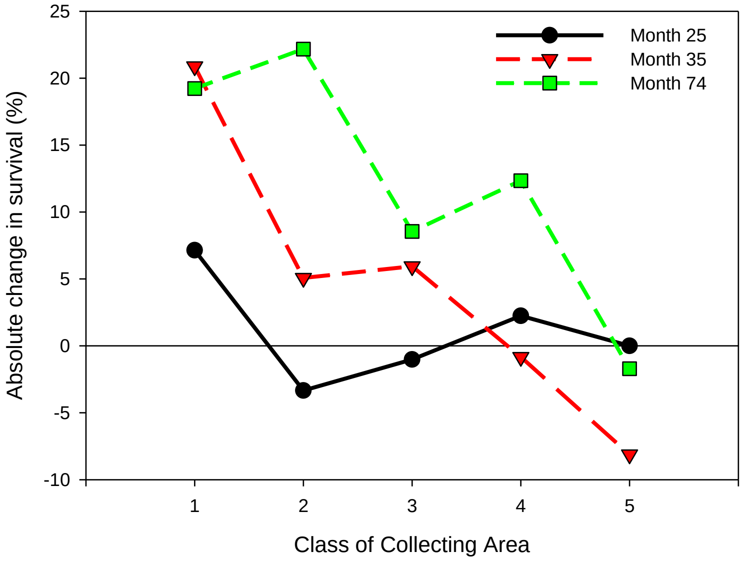

Figure 3. Difference of absolute change of seedling survival (%) between W1 and W0 two, three and six years after planting in relation to the upslope collecting surface area of the holes. See Table 2 for the correspondence between classes and collecting sizes.

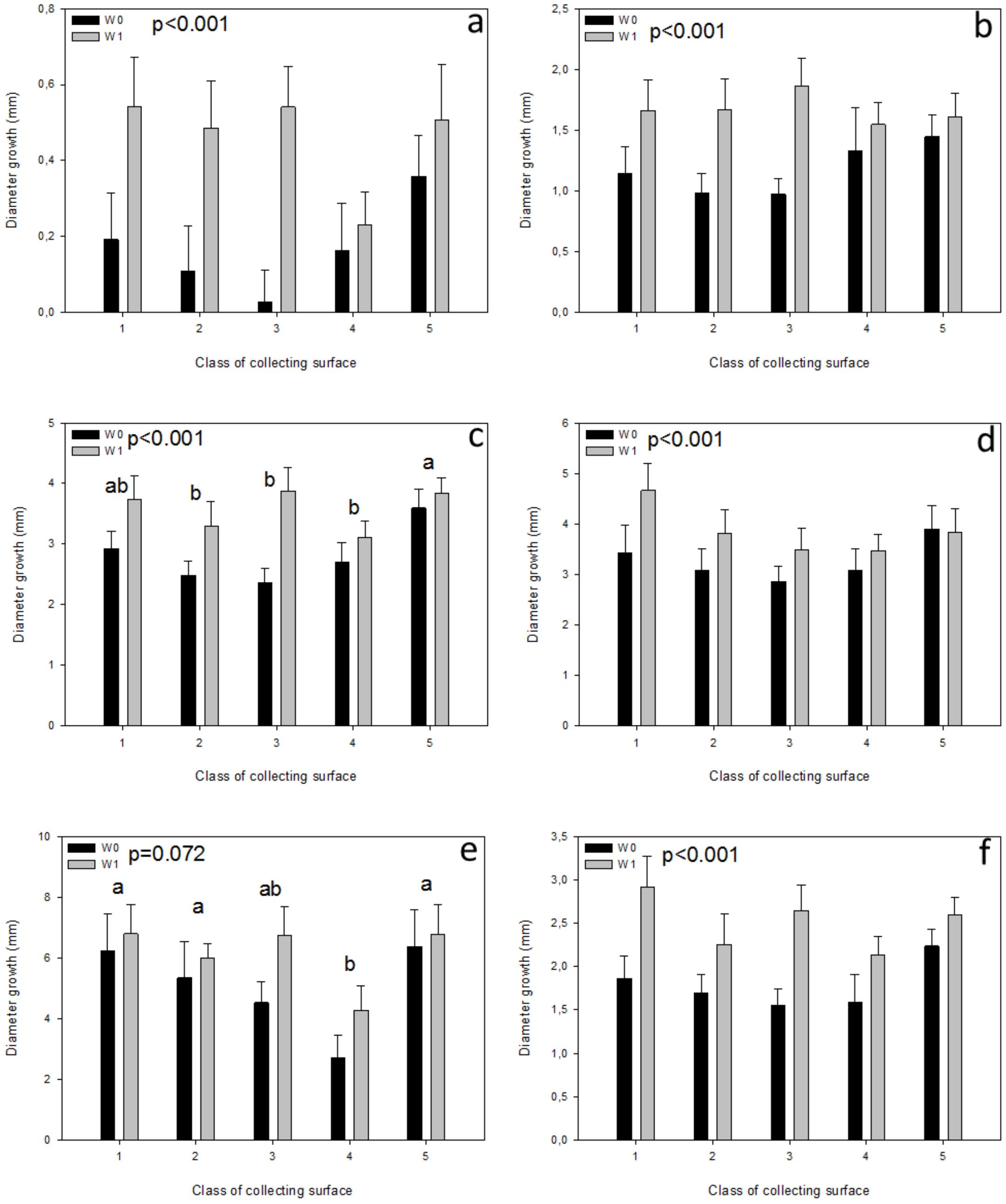

Figure 4. Absolute growth in seedling diameter (mm) since planting and a) July 2010, b) January 2011, c) July 2011, d) March 2012, e) January 2013 and f) April 2016. Different letters indicate significant differences between classes of collecting surface area. Differences between water availability treatments are shown by the *p* value in the legend.

The increase in water availability associated to the dry wells promoted growth significantly in all sampling dates, although this improvement was only marginal six years after planting (Fig. 4). As expected, dry wells effects were maximum during the first spring after planting (from April to July 2010) and differences decreased thereafter. At the last sampling date, control and seedlings with dry well grew in diameter 5.1 and 6.0 mm in average, respectively, representing 17.6% of relative increase in growth (Fig. 4). We observed significant effects of classes of collecting surface on seedling growth in two sampling dates. Two years after planting, in March 2012, seedlings with collecting areas of classes 2, 3 and 4 grew less than those in class 5 (F=2.365, p=0.053) with a relative increase in growth of 26.6%. Differences in growth between classes 4 and 5 increased until the end of the monitoring when seedlings in class 5 grew up to 78% more than seedlings in class 4 (F=3.576, p=0.008).

Basal area values integrate seedling survival and stem diameter growth in a single variable. The largest basal area value was observed in the planting holes with lowest collecting surface (class 1) when implemented with dry wells (20.5 cm^2), while the lowest basal area was in class 4 control holes (only 5.8 cm^2). Dry wells increased basal area records in all classes and sampling dates but in the largest class in January 2013 when we observed 10% relative reduction of basal area as compared to control holes (Fig. 5). In this date, holes with the smallest collecting area were very improved with the dry wells, showing a basal area value 80% higher than without the dry wells. All classes but the smallest one increased basal area between the two last sampling dates (2013 and 2016) when the recorded precipitation was well below the average, especially the extremely dry 2014.

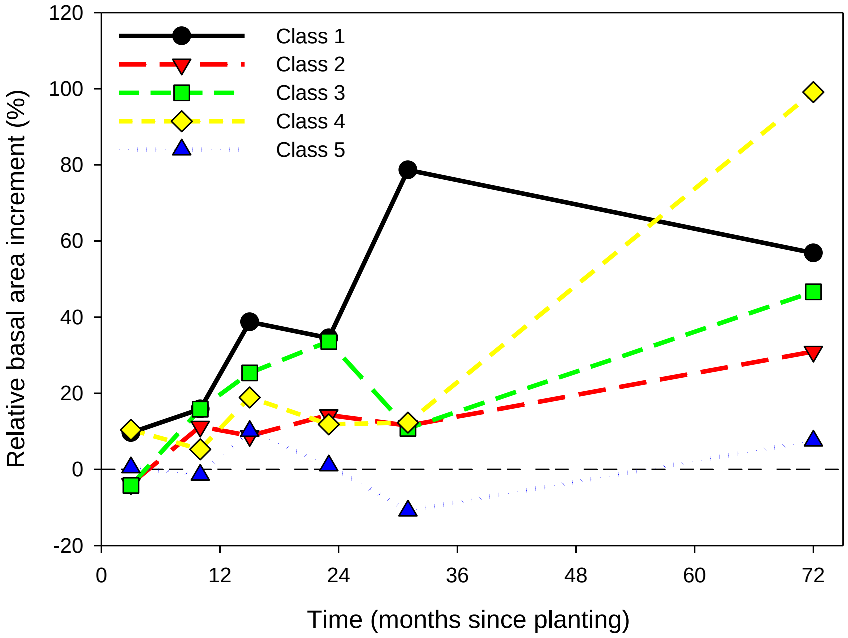

Figure 5. Difference of relative change of basal area values between dry wells and control planting holes in relation to the upslope collecting surface area of the holes. See Table 2 for the correspondence between classes and collecting sizes.

4. DISCUSSION

Microcatchments have been reported as an appropriate planting technique to improve the survival and growth of planted seedlings in the reforestation of Mediterranean degraded landscapes (De Simón *et al.*, 2008; Fuentes *et al.*, 2004; Saquete *et al.*, 2006). In addition to microcatchments, the results of this study confirm the effectiveness of using small waterproof surfaces to generate runoff and preferential paths (dry wells) to infiltrate water into the soil profile on the survival and performance of woody seedlings in water-limited environments (Valdecantos *et al.*, 2014). Large collecting surfaces or microcatchments might be positive for water harvesting and concentration only in runoff productive events. Sealing small pieces of the soil surface with waterproof materials makes runoff generation independent of rainfall event characteristics, both intensity and volume. This might be especially interesting in Mediterranean sites where up to 90% of total events are below 10 mm (Mayor *et al.*, 2011). However, too large impluvium areas or microcatchments implemented in steep slopes may collect runoff water with high energy that could cause harmful effects on the structure of the planting hole (Bainbridge, 2012) and, eventually, losing the sink capacity for water capture in further rain episodes and, hence, its functionality. The assessment of the soil surface microrelief conducted eight years after planting revealed that very few planting areas maintained the ability to retain water (Fig. 2), and this loss of the sink capacity was more pronounced as the microcatchment area of the planting hole increased (classes 3, 4 and 5). The larger the microcatchment area the higher the energy of the water and the higher the potential damages to the structure of the planting hole (Hammad *et al.*, 2006). In addition, the volume of overland flows susceptible to be captured in still functional holes was very low (<0.09 L in class 1). Most of the planting spots showed channels towards downslope suggesting that resources reaching the area may leak downslope and, eventually, produce physical degradation including net export of soil and resources. The planting spots were fully functional when seedlings were planted, and these retention structures kept their integrity for some years but we cannot identify when the planting holes started to loss their functionality. Anyway, planting holes, especially those with dry wells, were effective to act as sinks promoting organic matter accumulation and facilitating the establishment of spontaneous vegetation (Fuentes *et al.*, 2017).

Runoff generation depends on several factors which include, among others, the intensity and volume of the rainfall event and the properties of the soil surface such as stone and crust covers, either biological or physical (Calvo-Cases *et al.*, 2003; Cantón *et al.*, 2002). In calcareous soils of SE Spain, it has been observed thresholds of rainfall intensities in 30 and 10 minutes of 25 and 40 mm h^{-1}, respectively, to generate runoff (Calvo-Cases *et al.*, 2005), while minimum rain volumes required range between 6.6 and 10.8 mm (De Simón *et al.*, 2008). Displaying small waterproof surfaces forces runoff production and, hence, increases the amount of water volume that concentrates in the planting hole, being especially noticeable for low-intensity events (Valdecantos *et al.*, 2014). These authors established a precipitation threshold of 8 mm in a single event to produce runoff. During the study period, the two first years after planting were the ones with higher number of rain events above 8 mm (11 and 9 in 2010 and 2011, respectively). In fact, the planting year was the only in which precipitation was above the average of the historical series (14.4% more rainfall). On the contrary, the extremely dry 2014 and 2016 (only $\approx$ 45% of normal records) showed the fewest number of theoretical runoff productive events (five both years). These facts may help to explain the extremely and unusual high survival of planting seedlings during the first two years (very close to 100%), and the pronounced decline between the two last sampling dates. The implementation of dry wells was still effective in promoting growth during these drought periods.

Urgeghe & Bautista (2015) observed a positive relationship between the performance of *Olea europaea* planted seedlings and the source area upslope the planting hole. They recorded higher soil moisture when increasing the size of the microcatchment contributing to the planting hole. Our results suggest a lack of linearity between the size of the collecting surface and plant survival. In the same study site, not significant improvements in *Pistacia lentiscus* survival have been previously recorded in larger areas upslope the planting hole, when the larger the upslope length the statistically higher the survival of the seedlings (Urgeghe & Bautista, 2015). The improvement of plant survival and performance with increasing the impluvium collecting surface area has been also recorded in other non-Mediterranean drylands (Bayen *et al.*, 2016; Whisenant *et al.*, 1995). Li *et al.* (2006), with larger and wider range of classes of catchment areas (from 0 to 50 m^2), observed a positive linear relationship between planted individuals of *Caragana korshinskii* and the catchment size of the planting spot. They attributed this relationship to the increased soil moisture content at different soil depths. However, negative processes such as siltation and erosion can be triggered whether an excess of water from upslope reaches the hole (Bainbridge, 2012). We conducted the assessment of surface fluxes by aerial images eight years after planting and observed that the functionality of the planting holes was lost in almost all circumstances of microcatchment class and water availability treatment. The main function of soil preparation is to improve physical soil conditions and to optimize water capture and retention to allow early growth of, especially, seedling root systems but can produce important soil losses when unproperly implemented (Löf *et al.*, 2012). This issue is especially relevant in slopes that have gone beyond degradation thresholds and where ecosystem functionality have been lost as might be the case of our study site (Chirino *et al.*, 2009).

Our idea of precision restoration differs from that proposed by other authors (St-Denis *et al.*, 2018). We consider the analysis of surface water fluxes as a priority to design the planting spots in the restoration of drylands in addition to defining the most appropriate ecotechnologies for the establishment of specific plant species. Water resources are of outstanding importance in drylands and our study demonstrated that field planting techniques might be implemented and adapted to the spatial and physical features of the slopes to optimize cost:effectiveness ratio of ecological restoration of Mediterranean dryland sites.

5. CONCLUSIONS

Designing site preparation or planting techniques is a must in planning the restoration of degraded drylands. Our study highlights the relevance of planting spots as sink areas for natural surface fluxes and reveals the need of stable structures to retain essential resources on site. The higher the microcatchment area the lower the sink capacity at the medium-long term. Treatments aimed at forcing, directing and infiltrating runoff in the planting holes (waterproof surfaces and dry wells) are especially interesting when collecting surface areas are low. Conversely, they are not recommended when microcatchments are larger than 9.6 m^2. In dryland restoration planning, we suggest to conduct a study of water fluxes and slope microrelief before planting to identify more suitable areas for seedling establishment due to surface runoff concentration and spots where water optimization techniques, such as dry wells and waterproof surfaces, might be implemented to increase the likelihood of seedling establishment and further performance.

6. ACKNOWLEDMENTS

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Highlights

- Water fluxes in slopes in drylands are determined by biotic and abiotic features
- Sink areas can be recreated by ecological restoration through reforestation
- Relations between seedling performance and collecting area is not linear
- Dry wells are effective techniques, especially in holes with low collecting areas
- Microtopography and water fluxes should be considered when designing the restoration of drylands

Credit Author Statement

Author contributions

Athanasios Smanis: Investigation, Validation, Data Curation, Writing - Original Draft, Writing - Review & Editing. **David Fuentes**: Conceptualization, Methodology, Software, Formal analysis, Data Curation, Writing - Review & Editing. **Pablo Fuente**: Investigation, Validation, Data Curation, Writing - Original Draft. **Alejandro Valdecantos**: Conceptualization, Methodology, Validation, Supervision, Writing - Review & Editing, Funding acquisition

***Declaration of Interest Statement**

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: