

RESEARCH ARTICLE

The use of branch piles to assist in the restoration of degraded semiarid steppes

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Desertification is a major environmental problem in arid and semiarid regions. Tree plantation has been commonly employed to foster the recovery of degraded areas. However, this technique is costly, and their outcomes are often uncertain. Therefore, we evaluated an alternative method for the restoration of degraded semiarid steppes that involved the construction of branch piles to attract frugivores as potential seed-dispersing birds, promoting seed rain, and fostering the formation of woody patches. We measured the success of branch piles in terms of the number of bird visits and seed input compared to naturally occurring shrub patches. Generally, frugivorous birds visited branch piles less frequently than shrub patches. Yet, branch piles accumulated seeds of patch-forming shrub species. Seed rain was higher under patches of the dominant shrub *Rhamnus lycioides* than under branch piles. In contrast, woody patches and branch piles did not differ in seed input of the less abundant *Pistacia lentiscus* shrub. Our study demonstrates that branch piles are used by frugivorous birds and accumulate seeds of patch-forming shrubs. Branch piles may be a suitable method to promote the expansion of bird-dispersed plant species and restore semiarid wooded steppes. However, their efficiency largely depends on pile persistence and economic cost.

Key words: branch pile, desertification, fleshy-fruited species, frugivorous birds, seed dispersal, semiarid land

Implications for Practice

- Branch piles can be used to promote seed inputs into degraded semiarid steppes, as they are visited by frugivorous birds carrying seeds from near shrubs producing fruits.
- When we need to transport branches for piles from other localities, the economic cost of these piles is relatively high. Therefore, this method will be economically viable, if we devote attention to identify local sources of branches.
- Given the limitations to recruitment of seedlings in semiarid ecosystems, branch piles should be designed to last for years and be maintained. Branches of exotic invasive species should be avoided owing to the risk of spreading propagules of these species.

Introduction

Drylands cover 41% of the world's land surface and host a third of the human population (Safriel & Adeel 2005). Between 10 and 20% of these areas are highly degraded due to continued human use and environmental stress, exacerbated by climate change (Reynolds et al. 2007; Verstraete et al. 2009; Maestre et al. 2012). Desertification is a major global environmental problem, and important international efforts have been devoted to combat its causes and reverse its consequences. Recently, the United Nations Convention to Combat Desertification (UNCCD) established the Zero Net Land Degradation target (ZNLDD; Chasek et al. 2015). To achieve this goal, we need to improve our understanding of dryland systems, and develop

novel restoration techniques (Rost et al. 2010; Heelemann et al. 2012; Rost et al. 2011).

Regions located in the transition from arid to semiarid landscapes are particularly challenging for restoration, due to the high level of degradation, the difficulty of spontaneous regeneration, and the imminent risk of further degradation (Cortina et al. 2004; Reynolds et al. 2007). Seeding and planting woody species have been commonly employed techniques to restore degraded arid and semiarid areas (Cortina et al. 2011). Nonetheless, both techniques show significant limitations that often compromise the success of restoration programs. These include uncertainty in the climatic conditions following seeding and planting, risk of predation, and economic costs, which may become unaffordable (Maestre et al. 2012).

Woody patches are key components of plant communities in vast arid and semiarid areas, as they affect community composition, ecosystem functionality, and the provision of ecosystem services (Aguar & Sala 1999; Maestre et al. 2003; Ludwig et al. 2005). Patch-forming woody species have been increasingly

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planted for the restoration of degraded steppes, as spontaneous colonization may be too slow or absent (Cortina et al. 2004). These species are often dispersed by frugivorous birds (Herrera 2004; Zapata et al. 2014), and their dispersion is favored by the presence of resting places for birds, such as abandoned crop-trees and woody plants (Bonet 2004; Pausas et al. 2006). Resting places, such as woody perches, have been used to attract dispersers, promote seed rain, and foster succession, particularly in tropical and Mediterranean dry-subhumid areas (Galindo-González et al. 2000; Castro et al. 2010; Cavallero et al. 2013), but this technique has been scarcely tested in semi-arid environments (Heelemann et al. 2012).

We have evaluated the use of branch piles for the dispersal of seeds of key shrub species, as a step toward the restoration of degraded semiarid steppes in the southeastern Iberian Peninsula. Our aims are (1) to assess the use of branch piles by frugivorous birds, (2) to quantify the seed rain under branch piles and shrub patches, and (3) to explore the ecological, technical, and economic viability of this restoration technique.

Methods

The study was carried out in a steppe located in El Campello, in the southeastern Iberian Peninsula (38°27'52"N; 0°22'29"W; 150–200 m a.s.l.; Appendix S1, Supporting Information). It has a Mediterranean semiarid climate, with an annual mean rainfall of 374 mm (which is torrential and mostly autumnal), and a mean annual temperature of 18.3°C (11.2°C in January and 26.3°C in August). Soil is loamy-silty loam derived from marls and limestones (Lithic Calciorthid). The area is covered by *Stipa tenacissima* L. steppes, with scattered shrub patches largely dominated by *Rhamnus lycioides* Brot. (present in 97% of the patches) and *Pistacia lentiscus* L. (present in 31% of the patches; Amat 2015), whose seeds are known to be dispersed by frugivorous birds (Herrera 1984). During autumn and winter, the bird community in these steppes is dominated by passerines of the families Sylviidae and Turdidae that are known to include fruits in their diet and to act as seed dispersers in Mediterranean shrublands (Herrera 2004).

On 24 September, 2012, we built 32 branch piles with *Pinus halepensis* Miller branches, a native species that is widely used for afforestation in this region and hence is easily available. Pine branches were pruned in a plantation located 50 km from the study area. Branch piles were distributed to cover a gradient of altitude and aspect (SE, NW), across an area of circa 30 ha. Each pile measured 2.2 ± 0.4 m (average \pm SD) in diameter and 1.5 ± 0.2 m in height (Fig. 1), designed to mimic the shape and size of natural shrub patches. The closest shrub patch to each pile was used to compare bird use and seed rain between branch piles and shrub patches. We recorded the presence of *R. lycioides* and *P. lentiscus* females in the shrub patches. Of the 32 shrub patches studied, 23 included a female shrub; all included *R. lycioides* females and 7 also included *P. lentiscus* females. In the remaining nine shrub patches, eight included male *R. lycioides*, one was formed by *Juniperus oxycedrus* L.; none included male *P. lentiscus*. We measured height (m)

and diameter (m) of all branch piles and shrub patches, and estimated their volume (m³) assuming a cylindrical shape (Blanco & Navarro 2003).

All branch piles and shrub patches were monitored for the number of bird visits (number of birds of each species detected in each patch) and seed rain, between autumn 2012 and winter 2012–2013, when *R. lycioides* and *P. lentiscus* produce fleshy-fruits (Herrera 1984). Each branch pile and shrub patch was monitored for 2 days in autumn (between 1 and 4 October, 2012 and between 14 and 17 October, 2012) and 2 days in winter (between 26 December, 2012 and 4 January, 2013, and between 28 and 31 January, 2013). A team of four experienced ornithologists monitored bird visits. Each ornithologist observed one set of branch pile/closest shrub for 30-minute periods per day, during morning (8:00–10:00 hours), midday (12:00–14:00 hours), and evening (17:00–19:00 hours) sessions, to account for daily variations in bird activity.

Seed rain under shrub patches and branch piles was quantified by using an array of 45 × 30 × 10-cm plastic collector trays under each shrub patch or branch pile. Collector trays were placed on 24 September, 2012, and falling seeds were collected once per month until February 2013. We used between 2 and 10 trays per pile or shrub, depending on patch or pile size, which yielded an average of 0.58 ± 0.37 trays/m. We used the same average number of trays between piles and shrubs (piles: 0.64 ± 0.29 trays/m, shrubs: 0.52 ± 0.43 trays/m, $t = 1.30$, $p = 0.200$). Seeds were taken to the laboratory where they were cleaned and identified under a stereomicroscope. Collected seeds were divided into two groups: seeds that had been ingested by birds (free of pulp), and uneaten seeds (whole fruit).

We assessed differences in volume between piles and shrub patches using a one-way analysis of variance with one factor (type of perching place) and three levels: branch pile, shrub patch including at least one female of fruiting shrub of *R. lycioides* or *P. lentiscus*, and shrub patch not including females of these species. Volume differed between the three types of perching places ($F_{2,61} = 10.02$, $p < 0.001$) thus we included volume as a covariate in subsequent analyses. The number of bird visits and amount of seed rain per branch pile or shrub patch were analyzed in autumn and winter separately, by means of generalized linear models. Sampling dates in each season were pooled. For the number of bird visits, we considered as response variables the total number of frugivorous seed-disperser bird visits, and the number of visits of the most abundant species, *Sylvia undata* Boddaert, *Sylvia melanocephala* Gmelin, and *Sylvia cantillans* Pallas (i.e. four response variables by two seasons). As predictor variables, we considered volume of the branch pile or shrub patch and the type of perching place. For each response variable and season, we tested three models: (1) effect of perching place type, (2) interaction between perching place type and volume, and (3) an additive model of perching place type and volume. Each model was run considering a Poisson or a negative binomial distribution of errors, to take into account possible overdispersion (Quinn & Keough 2002). The best model for each response variable and season was selected on the basis of Akaike Information Criterion corrected for small sample size, (Burnham & Anderson 2002).

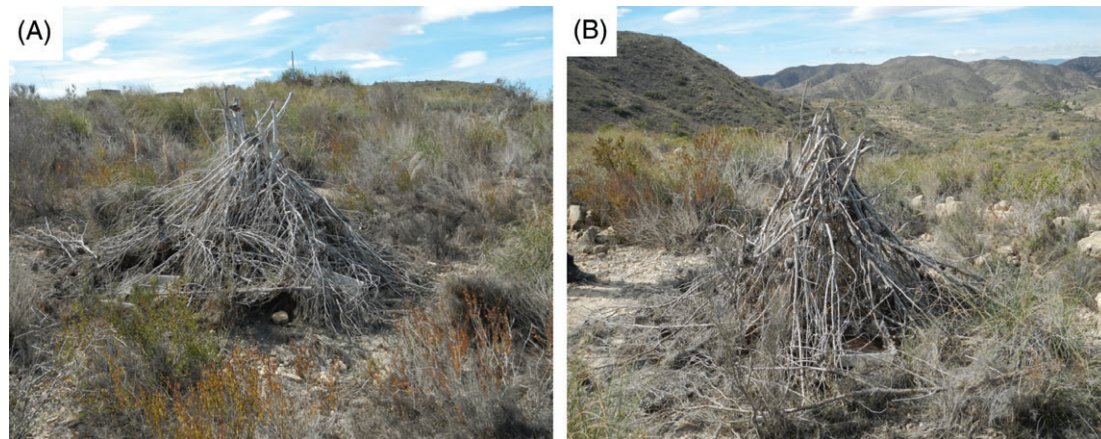


Figure 1. Branch piles built with intertwined *Pinus halepensis* branches at the onset of the study (24 September, 2012; A) and 27 months later (8 January, 2015; B).

Significance of predictors included in the selected model was assessed through analysis of deviance, dropping each term by turn. Tukey post-hoc tests were used to identify differences between types of perching places (Quinn & Keough 2002).

Noningested seeds were collected from under female shrubs of the same species but not under other shrub species or branch piles, thus we restricted our analysis to ingested seeds, as our focus was on seed dispersal. Seed rain (number of seeds per square meter per day) was calculated from ingested *P. lentiscus* and *R. lycioides* seeds collected in trays under each pile or shrub patch. Seeds collected in trays in early November and December 2012 were used to calculate autumn seed rain, while seeds collected in January and February 2013 were used to estimate winter seed rain. Therefore, we modeled four response variables, rain of ingested seeds of each shrub species in autumn and winter. We used the same predictors and model selection procedure described above to build seed rain models, but in this case, we used a Gaussian distribution of errors. Paired *t* test was used to compare seed rain under each species between seasons. All analyses were performed with R (R Core Team 2017).

We also estimated the cost of building branch piles as the sum of the individual cost of branch pruning in a dense pine plantation, branch packaging, 50 km transport and on-site deployment.

Results

Overall, we observed 203 visits of frugivorous birds belonging to 10 different species (Table S1). Among them, *S. undata* (80 visits) and *S. melanocephala* (43 visits) were the most common species. *Sylvia cantillans*, a trans-Saharan migrant, was abundant in autumn (21 visits) and absent in winter. Birds were more abundant in autumn than in winter (166 vs. 37 visits; Fig. 2). Although branch piles were visited by birds, shrub patches were visited more often (40 vs. 163 visits, respectively). The proportion of visits to branch piles was similar in autumn (19.3% of all visits) and winter (21.6%).

The models confirmed that frugivorous birds visited branch piles less often than shrub patches (Table S2). The same result

was observed for each bird species, with the exception of *S. melanocephala* in the winter, possibly as a result of a small sample size. Shrub patches, whether or not they included female shrubs, received a similar number of visits (Fig. 2). Patch size (estimated by volume) had a positive effect on the number of visits of frugivorous birds and the visits of *S. undata* in autumn.

All ingested seeds collected under shrub patches and branch piles belonged to either *P. lentiscus* (588 seeds; 60%) or *R. lycioides* (421 seeds; 40%). Overall, *P. lentiscus* seed rain was slightly larger than *R. lycioides* seed rain (0.49 ± 0.78 vs. 0.33 ± 1.16 seeds/m²/day, respectively). *Pistacia lentiscus* seed rain was similar in autumn (0.45 ± 0.74 seeds/m²/day) and winter (0.53 ± 0.82 seeds/m²/day; paired *t* = -0.593; *p* = 0.554). *Rhamnus lycioides* seed rain showed a marginally significant decrease in winter, compared to autumn (0.46 ± 1.47 and 0.19 ± 0.72 seeds/m²/day, respectively; paired *t* = 1.813; *p* = 0.075).

Pistacia lentiscus seed rain was similar under branch piles and shrubs in both seasons, but increased with the size of the pile or patch in the winter (Table S3). In contrast, in both seasons, *R. lycioides* seed rain was significantly higher under shrub patches that hosted female shrubs than under branch piles. Seeds of *R. lycioides* were not detected under shrub patches without females in the winter (Fig. 3).

The cost of each branch pile was 183 euros (USD 125). This figure accounted for around 46 euros (USD 56) for pruning-thinning a high-density *P. halepensis* stand, 38 euros (USD 47) for slash packaging and 50 km transport, and 99 euros (USD 121) of labor costs for deploying and building the piles (0.375 labor-days per pile). Most piles still persisted on 8 January, 2015, 2 years and 3 months after their establishment (Fig. 1) (A. Castillo-Escrivà, G. M. López-Iborra, & J. Cortina, personal observation).

Discussion

Our results show that, in the studied semiarid steppe, branch piles were used by seed-dispersing frugivorous birds, and

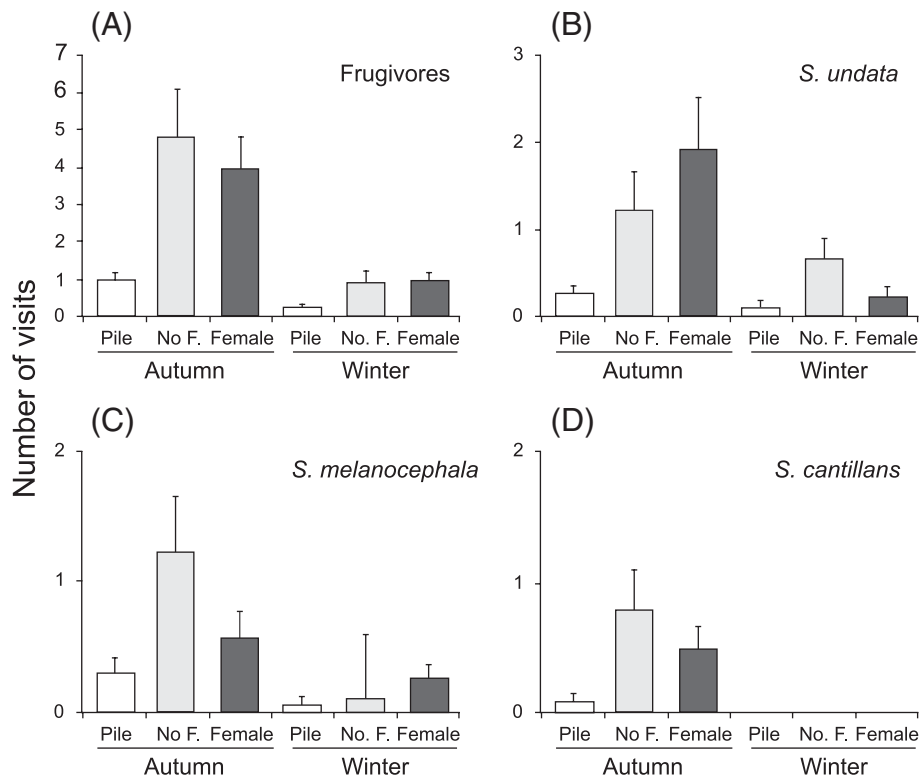


Figure 2. Mean (+SE) of the number of bird visits recorded during 30-minute observation periods in the three types of perching places for each season: Branch piles (labeled in the graphic as pile), shrub patches including at least one female individual of fruiting shrubs *Rhamnus lycioides* or *Pistacia lentiscus* (labeled as female) and shrub patch not including females of these species (labeled as no. F.), for all frugivorous seed-disperser birds (Frugivores; A) and for the three most abundant frugivorous bird species; *Sylvia undata* (B), *S. melanocephala* (C), and *S. cantillans* (D). Note different Y-axis scales.

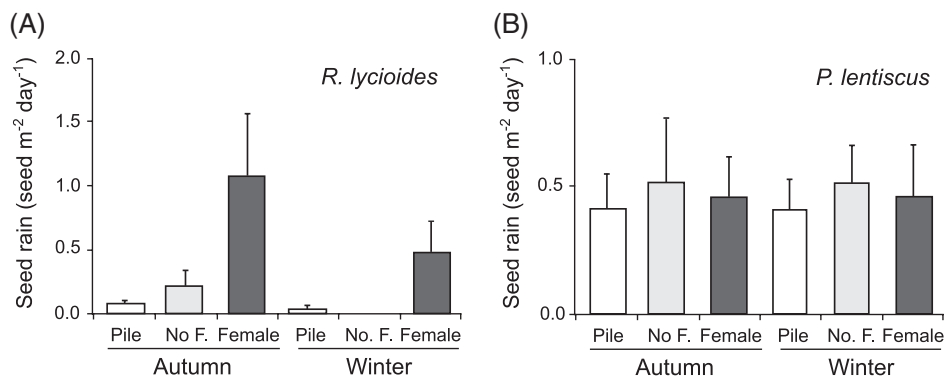


Figure 3. Mean (+SE) of the ingested seed rain of *Rhamnus lycioides* (A) and *Pistacia lentiscus* (B) in the three types of perching places studied: Branch piles (labeled in the graphic as pile), shrub patches including at least one female individual of fruiting shrubs *R. lycioides* or *P. lentiscus* (labeled as female) and shrub patch not including females of these species (labeled as no. F.). Note different Y-axis scales.

facilitate seed rain accumulation, supporting recommendations for their use by Rost et al. (2011), Castro et al. (2010), and Cavallero et al. (2013). Similar studies using artificial bird perches also showed an increase in seed accumulation (Heelemann et al. 2012). Verdú and García-Fayos (1996) observed that trees act as perches for birds in abandoned crops in the southeastern Iberian Peninsula, and promoted nucleation via seed establishment beneath the perches. Likely, if birds continued to use branch piles long term at our site, persistent seed rain could

foster seedling establishment in semiarid steppes where chances of spontaneous colonization are low (Amat et al. 2014).

The number of frugivorous bird visits to branch piles was lower than to shrub patches, especially in autumn. The lack of difference in visitation rate between shrub patches containing or lacking female fruiting shrubs may be due to the exploratory foraging behavior of the birds in search of food, especially insects. All the frugivorous birds studied also consume insects in autumn and winter (Jordano 1987). Insect abundance is

expected to be similar in male and female shrubs, which may explain similar number of visits to shrubs of both sexes.

Seed rain abundance of *Rhamnus lycioides* and *Pistacia lentiscus* differed between perching place types. *Rhamnus lycioides* ingested seeds were less abundant than *P. lentiscus* ingested seeds under branch piles, despite shrub patches being dominated by the former species. In contrast, the density of ingested seeds of *P. lentiscus* was similar under piles and shrub patches. This difference suggests that more *P. lentiscus* fruits were consumed by frugivorous birds than those of *R. lycioides*, or that the dispersal pattern of these species differ. The higher fat content of *P. lentiscus* fruits (>50 vs. <5% in *P. lentiscus* and *R. lycioides*, respectively; Herrera 1983) could favor their consumption. Lipid-rich fruits require slower food passage rates for efficient digestion (Fuentes 1994; Witmer & Van Soest 1998). Thus, protracted time in the gut may facilitate greater seed dispersal distances. Energetically, birds may require larger quantities of the less energetic *R. lycioides* fruits to fulfill their requirements. In this way, birds may increase time spent collecting fruits in *R. lycioides* shrubs and consequently the probability that excrements containing seeds of this species fall under *R. lycioides* females. Both processes could result in a more even abundance of *P. lentiscus* seeds under different perching types.

However, as the number of bird visits to shrub patches was higher than to branch piles, the similar *P. lentiscus* seed rain under both is remarkable. Differences could be explained by bird behavior on each substrate. The selection of roosting site may have a strong impact on seed rain distribution, as birds spend several hours in the same location while roosting. Birds often prefer dense vegetation for roosting to increase protection and reduce predation risk (Cody 1985; Antczak 2010). *Rhamnus lycioides* was the only species present in two thirds of shrub patches and its sparse foliage could make these shrubs less attractive for roosting than branch piles or shrub patches containing *P. lentiscus*.

Pistacia lentiscus seed rain under branch piles (0.49 seeds/m²/day) was somewhat higher than *P. lentiscus* seed rain in a meso-Mediterranean *Pinus halepensis* forest in northeast Spain (circa 0.21 seeds/m²/day; Rost et al. 2009), and much higher than in burned areas of this same forest (0.02–0.03 seeds/m²/day; Rost et al. 2009). *Rhamnus lycioides* seed rain under branch piles (0.06 seeds/m²/day) was still higher than the above figures for burned areas. Considering both shrub species, seed rain in the experimental branch piles was also higher than total seed rain measured in semiarid badlands in the southeastern Iberian Peninsula (circa 0.14 seeds/m²/day; García-Fayos et al. 1995). Therefore, our results show that branch piles may generate seed rain rates comparable to the ones found under natural perches in other Mediterranean habitats.

We found no evidence of seed predators removing seeds from collecting trays. Ants were never observed carrying seeds out of the trays nor we detected any sign of rodent presence. Previous studies have found a negligible effect of ants on the removal of *P. lentiscus* seeds (Aronne & Wilcock 1994; Barroso et al. 2013). The effect of seed predators may be expected to be larger under shrub patches where more seeds and noningested

fruits accumulate, which should attract more seed predators (Alcántara et al. 2000). In that case, the effect would have been to decrease differences between piles and shrubs.

Although we have shown the practicality of branch piles, other aspects should be considered prior to deployment of the method. First, seed rain density may be too low in other areas to ensure successful recruitment (García-Fayos & Verdú 1998). One could increase bird visits and seed rain density by supplementing resources such as food and water; however, this would increase management costs. Second, the efficiency of branch piles could be increased by maintaining their functional role for several years. For example, 2 years after the onset of the experiment, piles were still intact and functional. The longer branch piles persist, the lower the per year cost of management. Third, the efficiency of branch piles may also depend on landscape configuration and, particularly, on the distance to the nearest source of viable seeds. A major fraction of endozoochorous dispersal events occur at short distances, often no more than 100 m (Debussche & Isenmann 1994; Guttal et al. 2001). This represents a spatial constraint for the use of branch piles: they may only be useful to expand the limits of existing populations at relatively short distances. Thus, the restoration of large areas devoid of mature patch-forming shrubs may not be feasible using branch piles alone, unless a staggered approach is adopted. Branch piles facilitate colonization by local genotypes, thus reducing the risks of invasive species incursions, genetic contamination, and/or poor adaptation and establishment (Bischoff 2014). However, it is worth mentioning the risk of accidentally seeding invasive species with the use of allochthonous branches (Chalker-Scott 2007).

We did not test seed germination and seedling establishment in the field. The impact of branch piles on patch establishment is difficult to ascertain; however, it could be facilitated if seed rain under branch piles is persistent and environmental conditions suitable. Fallen needles and shade could create favorable soil conditions for establishment (Tongway & Ludwig 1996). However, after 4 years, the litter layer beneath the branch piles in our study was sparse compared to shrub patches. Due to the sparseness of the litter layer, detrimental effects of this layer on seed germination are unlikely (Navarro-Cano 2008).

Economic costs must be considered when assessing the applicability of the method. In our study, each branch pile cost 183 euros (USD 225). Considering an average shrub patch density in the studied steppes of 67 patches/ha (Rolo et al. 2016), the total cost of restoring 1 ha would be 12,261 euros (USD 15,075), provided that every pile generates a new patch. This amount is 2.5–6 times higher than costs of planting seeds (2,030–4,852 euros/ha; 2,491–5,953 USD/ha; Cuenca 2014). As the greatest cost was deploying branches and building piles (54%), the total cost could be reduced to 6,608 euros/ha (8,107 USD/ha), if branches were freely available on site. Unfortunately, the density and size of large shrubs and trees in *Stipa tenacissima* steppes was low, precluding the use of most locally accessible materials. It is also worth taking into account that branches forming the branch piles come from thinning/pruning works, the cost of which may be covered elsewhere. The most important figure would be the cost of establishing shrubs in the

long term that for traditional methods should take into account the survival rate of planted seedlings. Therefore, more research is needed to assess the effect of branch piles on seed germination and seedling establishment, and to compare them against the cost of patch establishment using traditional techniques over the long term.

An additional aspect to be considered in Mediterranean ecosystems is the possibility that adding branch piles could raise wildfire risk by increasing fuel accumulation and connectivity. Fire is uncommon in *S. tenacissima* steppes as biomass accumulation and fuel continuity are low (Cortina et al. 2009). The average extent and density of shrub patches in the study region is 11 m² and 67 patches/ha, respectively, representing 7% of the area (Amat 2015). Thus, branch pile density would need to be prohibitively high to significantly increase the risk of wildfire.

In conclusion, branch piles were frequently used by frugivorous seed-dispersing birds and fostered seed rain of keystone species in a semiarid steppe. Although an effective method, spatial limitations and high costs, compared to traditional seedling planting, may only justify its use under particular environmental and socioeconomic conditions.

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Supporting Information

The following information may be found in the online version of this article:

Appendix S1. Supporting information.

Figure S1. Location of the branch piles (red points) and shrub patches (green points) in the study area.

Table S1. Number of visits of frugivorous species to shrub patches and branch piles in autumn 2012 and winter 2013.

Table S2. Deviance analysis for the variables included in the best model to explain the number of visits of all frugivorous birds (dispersers) and the most abundant species, *Sylvia undata*, *S. melanocephala*, and *S. cantillans*, in autumn and winter.

Table S3. Tests (ANOVA) of the variables included in the best model to explain ingested seed rain of *Rhamnus lycioides* and *Pistacia lentiscus* (seeds per square meter per day) in autumn and winter.

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