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Short communication

# Habitat complexity and individual acorn protectors enhance the post-fire restoration of oak forests via seed sowing

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ABSTRACT

Oak reforestation via direct sowing has advantages over planting for economic and plant-morphological reasons, but the risk of high acorn predation usually dissuades land managers from using this method. In a previous study we hypothesised that overcoming acorn predation would require both large-scale solutions to reduce predation by large mammals – which we had effectively obtained through ecosystem management leading to greater habitat complexity – and small-scale protection to tackle predation by small mammals – which we had been unsuccessful to encounter. In this study we aimed to test this hypothesis under the same management areas but with a new acorn-scale protective device named seed shelter. We carried out an acorn predation experiment in Sierra Nevada (S Spain), in a burnt area with three replicates of each of two post-fire management treatments: non-intervention (NI), with high habitat complexity due to the abundance of lying burnt trees, and salvage logging (SL), with low habitat complexity due to the previous felling and piling of the tree trunks and chopping of the branches. In each replicate we sowed 50 acorns with seed shelter and 50 acorns without (N = 600 acorns). After 129 days, predation by rodents averaged 17% for control acorns, while the seed shelter reduced this to nil. Predation by boars (17.5% overall) was not affected by the seed shelter but was reduced to one-sixth in the NI treatment (5% vs 30% in SL), so we obtained the lowest overall predation rates in the combined NI + seed shelter treatment (5%). We thus corroborated our hypothesis that combining large-scale management with an acorn-scale protection can greatly increase the success of sowing. We expect these outcomes to increase the effectiveness of direct sowing and to raise the share of this practice in reforestation, especially for species that develop best with direct sowing such as oaks.



## 1. Introduction

Millions of hectares of land are reforested every year to counteract deforestation and the degradation of natural ecosystems. Oaks (*Quercus spp.*) are frequently used for reforestation (e.g., EEC regulation no. 2080/92), as they are widely distributed across the Holarctic. Oaks provide numerous ecosystem services (Marañón et al., 2012), but they are encountering population decline and difficulties in their regeneration in many parts of their distribution range (Dey et al., 2008; Pulido and Díaz, 2005; Thomas et al., 2002). Much hope, effort, and money are thus placed into reforestation with oaks, yet stories of low success are very common (Dey et al., 2008; Navarro Cerrillo et al., 2005; Rey Benayas et al., 2005).

Seedling planting and seed sowing are the two possibilities for reforestation with oaks. While planting oaks has the advantage of using already-established seedlings, it often renders high seedling mortality and/or low-quality plants (Rey Benayas et al., 2005 Zadworny et al., 2014), as nursery-grown seedlings often present root architectures that are suboptimal for field conditions (Tsakaldimi et al., 2009). In contrast, sowing has the advantage of producing seedlings that are better acclimated to local conditions, besides having about one-half to one-third of the economic cost of planting (Bullard et al., 1992; King and Keeland, 1999; Madsen and Löf, 2005). However, sowing is usually opted out because of the frequent high levels of acorn predation and the uncertainty that results from oscillations in predator populations (Dey et al., 2008; Madsen and Löf, 2005). Finding a way to reduce acorn predation could thus increase the success and reliability of acorn sowing and of forestation practice in general.

Reducing seed predation can be achieved by taking advantage of habitat features that affect the activity of seed predators. For example, areas covered by shrubs or coarse woody debris can

*Abbreviations:* BWM, burnt-wood management treatment(s); SL, salvage logging treatment; NI, non-intervention treatment.

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represent a physical obstacle for foraging by ungulates (Ripple and Larsen, 2001), although they can also provide food and shelter for rodents (Gómez, 2004). Due to such contrasting effects of habitat on different predator guilds there is hardly any optimal solution to increase acorn survival to predation. In a previous study in an area where the management of wood after a forest fire in Sierra Nevada (S Spain) generated areas with low or high habitat complexity (Leverkus et al., 2013) we concluded that combining high habitat complexity at a large scale (which reduced foraging by wild boars; Leverkus et al., 2013; Puerta-Piñero et al., 2010) with some small-scale protection from rodents might effectively increase acorn survival. However, such small-scale protection was yet to be discovered – we tested deeper burial and a chemical repellent but without much success (Leverkus et al., 2013).

Devices designed to represent a barrier for seed predators are usually ineffective, large, expensive, difficult to handle, or a combination of those (Dey et al., 2008; Madsen and Löf, 2005; Pemán et al., 2010; Reque and Martin, 2015). In this short communication we test the effectiveness of a new, simple device – named seed shelter (Castro et al., 2015) – designed to protect individual acorns from small predators in areas where different management schemes have led to greater or lower habitat complexity due to the presence or absence of deadwood. For this we performed an acorn predation experiment in the above-mentioned post-fire habitats. Our working hypotheses were that: (i) the seed shelter device would represent a physical barrier that would reduce acorn predation by rodents, and (ii) the use of the seed shelter in areas with greater habitat complexity would yield the greatest acorn survival due to the cumulative effect of the seed shelter on reducing predation by rodents and of habitat complexity on reducing foraging by ungulates (wild boars). Overall, we expect to find a way to turn acorn sowing into an effective and reliable method to produce high-quality oak seedlings.

## 2. Materials and Methods

### 2.1. Study site

This study was carried out in the Sierra Nevada National Park (S Spain), in an area of the Lanjarón municipality where a fire burned about 1300 ha of pine afforestations in September 2005. The area has Mediterranean climate, with hot, dry summers and mild, wet winters. Holm oak forests (*Quercus ilex* subsp. *ballota* (Desf.) Samp.) are the main climax vegetation in the area (Valle, 2003). The main acorn predators are wild boars (*Sus scrofa*) and rodents like *Apodemus sylvaticus* and *Mus spretus* (Gómez and Hódar, 2008; Puerta-Piñero et al., 2010).

In spring 2006, an experimental site was established in a burnt *Pinus pinaster* and *P. nigra* afforestation at 1477 m a.s.l. to test the effects of burnt-wood management on different processes related to ecosystem restoration (37°57′ N, 3°29′ W; see supplementary kml file). This site included three replicates of each of two burnt-wood management (BWM) treatments, which had an area of $2.0 \pm 0.2$ ha (Leverkus et al., 2012). The treatments were: (a) salvage logging (SL), where the burnt tree trunks were felled, separated from their main branches and piled, and the remaining woody debris was mechanically masticated; (b) non-intervention (NI), where no action was taken and all the trees had fallen by 2010. The physical structure of the SL treatment was an open area easily accessible by humans, while the NI treatment was covered in branches and trunks that complicated movement (Leverkus et al., 2013; Puerta-Piñero et al., 2010). For further details on the study area and the experimental site, see Castro et al. (2012) and Leverkus et al. (2012, 2013).

### 2.2. Acorn predation experiment

In January 2014 we began an experiment to test the effects of habitat complexity and individual acorn protection on seed predation. For this, we established 50 sowing points per BWM replicate (6 replicates), and in each point we sowed two *Q. ilex* acorns 30 cm away from each other: one with and one without seed shelter (600 acorns in total). The seed shelter (patent #201331441, University of Granada; Castro et al., 2015) consists of two identical truncated cones or pyramids joined at their larger opening and filled with substrate. The rationale is that a large seed could be held in the wide middle of the seed shelter and that the small upper and lower openings would be large enough to allow the stem and the roots to grow out, yet small enough to prevent the entrance of a rodent. For the present study we used prototypes made of polypropylene (Fig. 1).

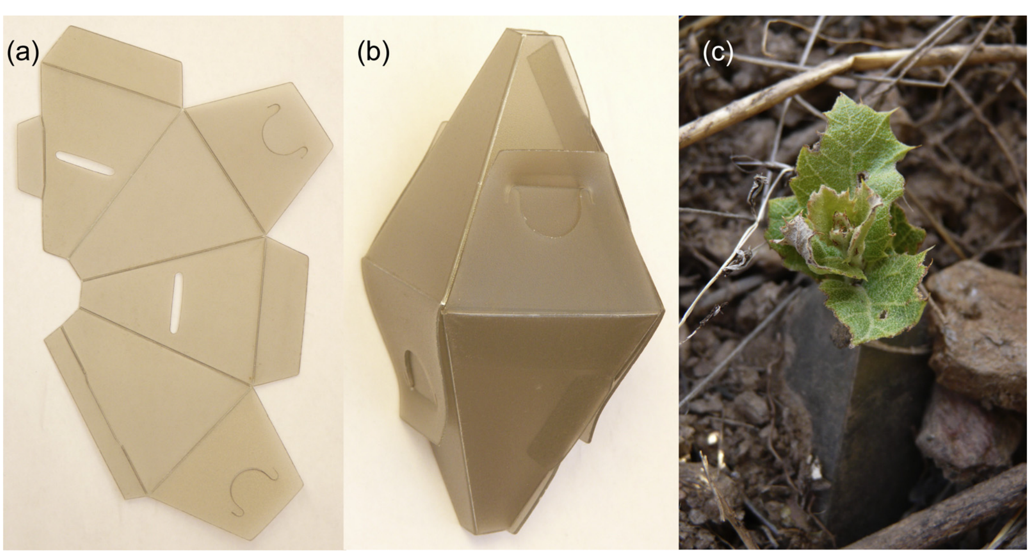


**Fig. 1.** Photos of the seed shelter prototype used for this study. Two identical flat shapes, punched out of 0.8 mm polypropylene sheets (a), were folded together to create truncated pyramids, which were then assembled with simple folds and slots to create the complete seed shelter (b). Before joining the two parts, they were filled with substrate [1/3 sand and 2/3 peat (Kekkilä Garden Brown 025 W)] and an acorn was placed in the middle. The entire device was then placed belowground in the field with its upper opening at ground level (c), which left the acorn within at 5–6 cm depth. The acorns without seed shelter were placed at the same depth.