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Does shrub recovery differ after prescribed burning, clearing and mastication in a Spanish heathland?

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Abstract Prescribed fire is used to reduce wildfire hazard in many ecosystems worldwide. However, alternative techniques such as mechanical fuel reduction are easier and safer to carry out under a wide range of weather conditions. Nonetheless, information about the associated environmental effects is still scarce, although critical to help land managers select the most appropriate treatment in terms of efficiency and long-term sustainability. In this study, we compared the effects of prescribed burning, clearing and mastication on shrub cover recovery in a heathland dominated by the resprouters *Erica australis* L. and *Pterospartum tridentatum* (L.) Willk. in Galicia (NW Spain) during the first 4 years after application of the treatments. The three treatments did not affect recovery of shrub cover or height during the 4-year period after application. Moreover, the treatments did not affect species richness, evenness or alpha diversity during the 4-year study period. The temporal patterns of post-treatment shrub recovery depended on the resprouting ability of the species present before application of the treatments. The recovery of *Pterospartum tridentatum* cover was faster than that of *Erica australis*, whereas the height recovery was similar. The results show that the three fuel treatments compared in the present study did not hinder shrub recovery and are, thus, feasible management alternatives for these heathlands.

Keywords Prescribed burning · Mastication · Clearing · Resprouting · Heathland

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Introduction

Shrubland areas throughout the world are often affected by wildfire (Whelan 1995; Bond and van Wilgen 1996; Bradstock et al. 2002). Fuel reduction treatments are used to modify fuel quantity and continuity and thus to reduce the risk of occurrence of high-intensity, high-severity wildfires. Prescribed burning is often the first option used in an attempt to emulate historical disturbance regimes, thus contributing to the conservation of ecosystem structure and function (Davies et al. 2008; Schwilk et al. 2009; Fernandes et al. 2013). Prescribed fire is a flexible technique that can be applied to fairly inaccessible areas at a relatively low cost. However, application of the technique is limited by the risk of fire escaping and the difficulty in determining windows of suitable meteorological conditions. Mechanical methods are often used as a surrogate for the actions of fire

(Schwilk et al. 2009; Porto et al. 2011; McIver et al. 2013), although these methods also have some limitations (they are more costly than prescribed fire and their use is also limited by the slope and stoniness of the ground). Moreover, scientifically based information on the ecological implications of different fuel treatments in shrub-dominated ecosystems is not widely available to forest managers.

Fuel reduction affects plants differently, depending on the species traits (resprouters or obligate seeders), thus leading to changes in community composition (Pelton and Conran 2002; Keeley 2006; Potts and Stephens 2009; Gosper et al. 2010; Bristow et al. 2014). For example, high-severity fire can kill below-ground portions of shrubs and damage the bud bank, thus decreasing the number of resprouting shoots (Cruz et al. 2003; Enright et al. 2011). Mechanical treatments that use forest machinery, such as mastication, can damage the bud bank through mechanical impact on the basal portion of the stems or by compaction. However, treatments such as clearing only affect the above-ground biomass (Fernández et al. 2013c).

In the northern Spain, fire prevention planning in shrub-encroached areas is critical because of the large number of fires that occurs annually (about 8,000 fires per year in the period 2001–2010: MMA 2010) and the high population density in urban–wildland interface areas in the region. *Erica australis* L. and *Pterospartum tridentatum* (L.) Willk are common components of shrubland areas in northern Spain, and their persistence mainly depends on the resprouting ability after perturbation. Previous research in this community showed limited seedling emergence after fuel reduction treatments (Fernández et al. 2013b). Moreover, prescribed burning, clearing and mastication did not affect the resprouting ability of the above-mentioned species in the first months after application of the treatments (Fernández et al. 2013c). However, it would be useful to know whether the response also reflects a lack of differences in recovery of the plants 4 years after treatment application.

In the present study, we monitored the response of the mature vegetation during the 4 years following application of prescribed burning and two mechanical fuel reduction treatments in a Galician heathland, to assess whether the effects of mechanical fuel reduction resemble those of prescribed burning, in terms of vegetation recovery and diversity. We also tested whether mastication and clearing are equivalent options for managing these heathland systems.

Materials and methods

Study site

The study was carried out in the Edreiras Mountains (42°8′02″N–7°26′17″W; 1,330 m a.s.l) in the province of Orense (NW Spain). The mean slope in the study area is 10 %. The shrub community is a typical mixed heathland dominated by *E. australis* L, ssp. *aragonensis* (Willk). The other main woody species present are *P. tridentatum* (L.) Willk. and *Halimium lasianthum* ssp. *alyssoides*. The climate in the area is Mediterranean. The average rainfall is about 1,100 mm year^{-1} with a marked dry period of 3 months in the summer. The mean annual temperature is 10 °C, with a pronounced degree of diurnal thermal contrast. The soils are Alumi-umbric Regosols (FAO 1998) developed on schist. Historically, the site was repeatedly burned at a low frequency (every 5–10 years) by pastoral burning. However, since implementation of a fire exclusion policy (since the 1960s), the site has been burned by summer wildfires. Cattle and roe deer are frequent in the area. At the beginning of the experiment, the time since the last fire was 7 years.

Experimental design

Twelve experimental plots (each 50 × 50 m) were installed on a hillslope in the study area. A randomized block design including three different fuel management treatments was implemented. The treatments were prescribed burning, shrub mastication and shrub clearing, and each treatment was applied to four replicate plots. Ten subplots (2 × 2 m) located in a grid within each plot were used for measuring the plants. The experimental area was surrounded by electric fencing to prevent it from being grazed by cattle and roe deer.

Treatments

The fuel treatments were implemented in spring 2010. Prescribed fire plots were burned by a strip head fire. Further information on the fire behaviour and thermal regime during burnings is available in previously published papers (Fernández et al. 2013a, b, c).

Mastication was performed using a steel track tractor with a front-mounted rotating-toothed drum, which shredded above-ground biomass into a patchy <5 cm layer of small diameter woody debris that was left on the soil surface. The operator performed systematic passes through the vegetation to achieve treatment homogeneity. In the shrub clearing treatment, shrub was manually cut from the base of the plants with a trimmer and the residue was removed from the plots.

Field measurements

The above-ground vegetation was surveyed in each subplot within each experimental plot. We measured plant cover by the line intercept method (Kent and Coker 1992) along five transects in each subplot. Shrub height was also measured at 0.5-m intervals along each transect. We identified all species present in each subplot and their frequency was recorded by counting the number of individuals of each species. The Shannon index (Shannon and Weaver 1949) was used to determine the alpha diversity in the plot as well as the components, richness and evenness (Pielou 1969).

Experimental plots were monitored immediately before fuel reduction treatments (spring 2010) and every 6 months during the first 4 years after application of the treatments (2010–2014).

Data analysis

A linear mixed-model ANCOVA (Zuur et al. 2009) was used to test the effect of the treatments on shrub cover and height, alpha diversity, species richness and evenness. Treatment (prescribed burning, clearing and mastication) was considered as a fixed effect, while plots and subplots were included as random effects. Time since treatment (date) was included as a covariable. Only post-treatment dates were included in the analyses. After identifying significant mixed effects, post hoc pairwise comparisons (with Bonferroni adjustment for multiple comparisons) were carried out to determine any differences between treatment effects. Residuals were tested for autocorrelation, normality and homogeneity of variance.

Statistical analyses were carried out with package lme4 from the R statistical software (Core Team Development 2014).

Results

Effects on vegetation cover and height

There were no differences between the effects of fuel reduction treatments on the total vegetation cover (Table 1). Vegetation cover increased gradually throughout the period after application of the treatments (Fig. 1). Four years after fuel reduction treatments, the total vegetation cover was, on average, 7.1 % greater than the pre-treatment values.

Separate analysis for each shrub species or group of species showed that treatments did not differ in their effects on recovery of plant cover (Table 1). At the end of the study period, *E. australis* had recovered on average 75 % of its pre-treatment ground cover (Fig. 2a) and *P. tridentatum* cover was 3 % greater than the pre-treatment value (Fig. 2b). Ground cover by *H. lasianthum* ssp. *alyssoides* increased by 193 % and ground cover by grasses was 12 times greater than before the treatments (Fig. 2c, d).

Although the treatments reduced the height of the three main shrub species (Fig. 3), no differences between treatment effects were observed in any case (Table 1). *E. australis*, *P. tridentatum* and *H. lasianthum*

Table 1 Linear mixed-model tests of treatment effect on vegetation variables

Variables	*F*	*P*
Total vegetation cover	0.619	0.4315
Erica australis cover	2.852	0.0671
Pterospartum tridentatum cover	0.159	0.6904
Halimium lasianthum ssp. *alyssoides* cover	0.113	0.7370
Grass cover	0.033	0.8568
Erica australis height	0.734	0.3917
Pterospartum tridentatum height	0.846	0.3578
Halimium lasianthum ssp. *alyssoides* height	1.074	0.3000
Alpha diversity	0.096	0.7531
Species richness	0.050	0.8202
Evenness	0.105	0.7461

Numerator degrees of freedom = 1; Denominator degrees of freedom = 2

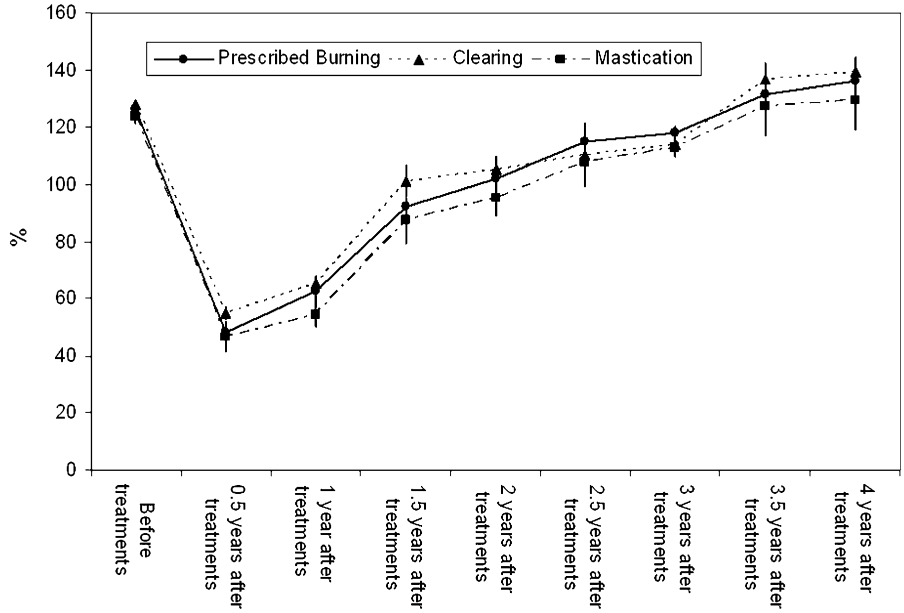


Fig. 1 Mean percentage of ground cover by vegetation during the first 4 years after fuel treatment application in an *E. australis*-dominated shrubland. *Vertical bars* are standard errors

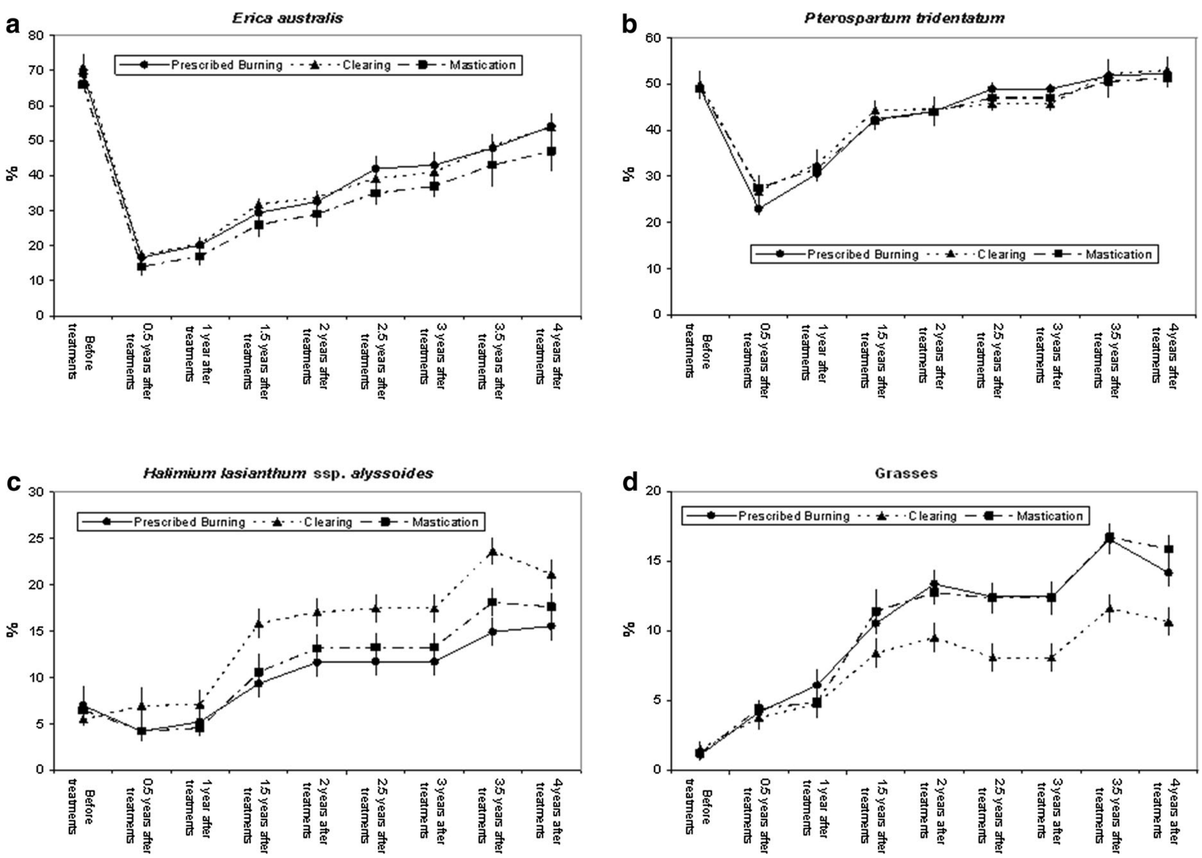


Fig. 2 Mean percentage of ground cover by the main plant species during the first 4 years after fuel treatment application in an *E. australis*-dominated shrubland. *Vertical bars* are standard errors

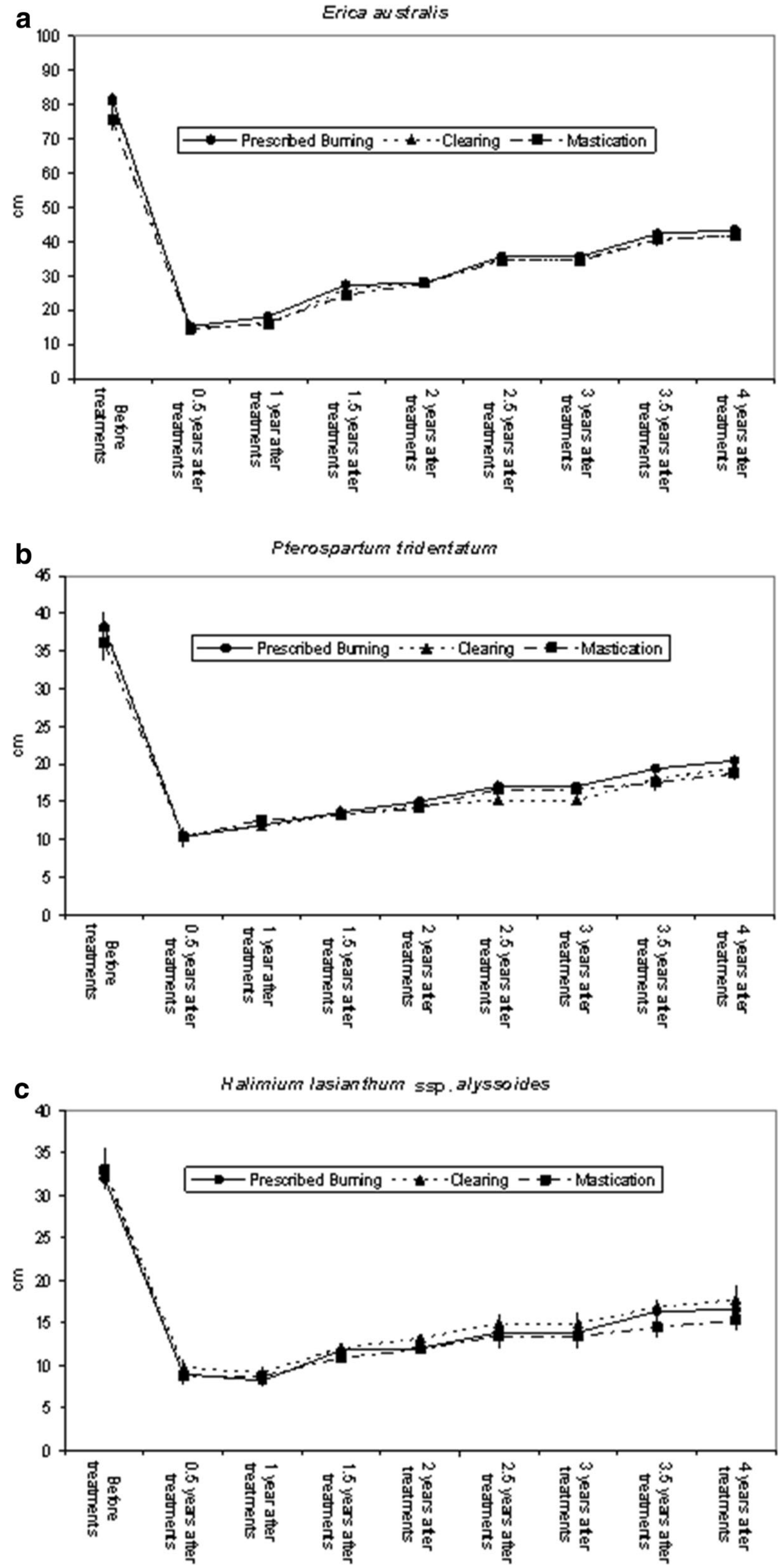


Fig. 3 Mean plant height for the main shrub species during the first 4 years after fuel treatment application in an *E. australis*-dominated shrubland. *Vertical bars* are standard errors

ssp. *alyssoides* recovered more than 50 % of their initial height by the end of the study period (Fig. 3).

Effects on community composition-related parameters

Prior to application of the treatments, six plant species were identified (Fig. 4), with *E. australis* and *P. tridentatum* being the predominant species in all plots. The species identified during the study period are listed in Table 1 SM.

The treatments did not affect species richness, alpha diversity or evenness (Table 1).

Discussion

The observed lack of any significant differences between the effects of prescribed burning, mastication and clearing on the recovery of shrub cover in the present study is consistent with previous findings in an *Erica umbellata*-dominated heathland in northwestern Spain (Fernández and Vega 2014). No differences in recovery of shrub cover after burning and clearing were observed in an *E. australis*-dominated heathland in northern Spain under a similar climate (Calvo et al. 1998, 2002a, b, 2005), although unfortunately there is no comparable information on the effect of mastication. In a Californian chaparral, Potts et al. (2010) observed that shrub cover was greater after prescribed burning than after mastication, unlike in the present study. These authors observed a significant increase in shrub germination after fire, which was not observed in the present study, in which plant regeneration after the treatments mainly depended on resprouting. Indeed, Fernández et al. (2013b) observed a depleted soil seed bank in the same site as this study, with almost no seed germination in the field, despite the fact that germination of *P. tridentatum* and *H. lasianthum* is known to be stimulated by soil heating under laboratory and greenhouse conditions (Rivas et al. 2006; Fernández et al. 2013b).

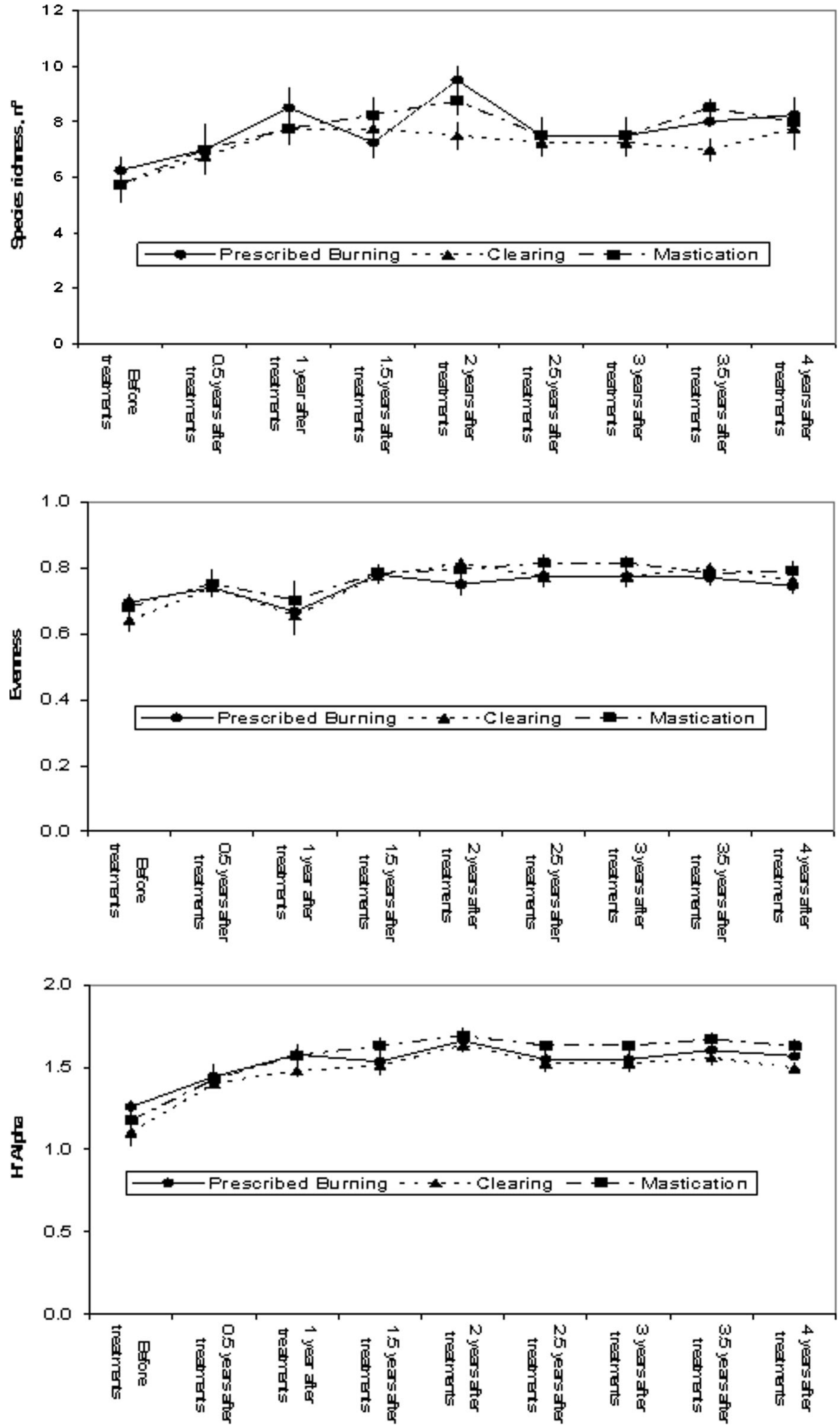
Recovery of pre-treatment shrub cover was quite rapid in the present study (total cover already exceeded the initial values 3.5 years after treatment application), whereas in similar Mediterranean heathlands recovery did not occur until 4 years after clearing and burning (Calvo et al. 1998, 2002a, b, 2005). The rate of recovery of *E. australis* measured in the present study (75 %) was slightly higher than the 60 % recorded in a heathland with similar initial cover (Calvo et al. 2002b). The different responses may be explained by differences in edaphic and climatic conditions and treatment execution. *E. australis* is characterized by rapid resprouting after disturbance as the root system remains intact and the plant only has to recover the above-ground biomass. The large lignotuber of this species has been suggested to be an evolutionary adaptation to summer drought and low temperatures in winter (Cruz et al. 2002). Moreover, Fernández et al. (2013a) observed a positive effect of soil organic layer depth on *E. australis* resprouting vigour after prescribed burning, probably because it minimizes water evaporation from soil in summer.

It is not possible to compare the increase in pre-treatment cover values observed for *P. tridentatum* and *H. lasianthum*, as the above studies were carried out in *E. australis* heathlands with different species composition. The results of the present study suggest a strategy of recolonisation of the bare surrounding space in the absence of competition (Calvo et al. 2002a; Marcos et al. 2004) and could lead in the long term to shift the community composition to a heathland with a higher preponderance of *P. tridentatum* relative to the pre-treatment values.

The observed lack of treatment effect on shrub height was similar to findings of other studies (Calvo et al. 1998; Potts et al. 2010; Fernández and Vega 2014). In the present study, the increase in the height of *E. australis* during the study period occurred faster than the increase in ground cover, suggesting some competition with *P. tridentatum,* for which ground cover had increased above the pre-treatment values, but only 52 % of the initial height was reached 4 years after treatments. Calvo et al. (1998) and Marcos et al. (2004) found that the most pronounced increase in height occurs once the plants again occupy the space they had originally covered in a heathland dominated by *E. australis* but without the presence of *P. tridentatum*. It is not yet known whether the initial delay in *E. australis* recovery will endure, shifting the community composition.

The clear dominance of herbaceous species detected in previous studies immediately after burning or mechanical treatments in various shrubland communities (Mallik and Gimingham 1985; Calvo et al. 2002a, c; Perchemlides et al. 2008) was not observed in the present study. The observed lack of treatment

Fig. 4 Mean values for species richness, evenness and alpha diversity during the first 4 years after fuel treatment application in an *E. australis*-dominated shrubland. *Vertical bars* are standard errors



effects on number of species and on community composition-related parameters is consistent with findings in other shrub communities such as Mediterranean (Calvo et al. 2005) and Atlantic heathlands (Fernández and Vega 2014) and Californian chaparral (Perchemlides et al. 2008; Sikes and Muir 2009; Potts et al. 2010), but contrasts with observations in Australian heath communities (Pelton and Conran 2002; Gosper et al. 2010). The low species richness, the high evenness values and the low alpha diversity measured in the present study, relative to those found in previous studies, appear to be driven by *P. tridentatum* and *E. australis* dominance in the studied heathland.

Conclusions

Fuel reduction treatments must be evaluated from management and ecological perspectives. The treatments should reduce the risk of severe wildfire while maintaining ecosystem integrity. Taking both objectives into account is critical in managing areas that have undergone changes from historical conditions, as in many fire-prone shrublands in Spain.

The shrub species under study responded similarly to the different treatments, showing strong resilience. This implies that mechanical methods may be useful alternatives to prescribed fire in regard to vegetation recovery. However, other aspects of fuel treatments must also be considered: for example, erosion risk and nutrient losses may be higher after prescribed fire, while mechanical treatments may increase fire hazards in the short term as fine dead fuel is left on the ground.

Fuel treatments significantly affected the heathland community under study in the short and medium term, with implications for the frequency of application. An increase in leguminous species, as detected in this study, may be beneficial for soil fertility and for pastoral purposes, resembling the desired effects of ancestral pastoral fires that aimed to increase leguminous species for grazing.

The results obtained in the present study can be used to guide the management of other fire-prone Mediterranean shrublands.

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