Role of fires, herbicides and fertilizer in manipulating shrub/grass balance in Mediterranean grasslands

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Abstract. The decline of traditional pastoral systems has highlighted the problem of managing shrub encroachment in shrublands of the Mediterranean region, especially in marginal habitats. Ephemeral grasslands appear after fire in Mediterranean shrub communities on phosphorus-deficient soils, but natural successional processes rapidly led to their dominance. In a study, aimed at reducing the rate of successional change and extending the period of grassland dominance, phosphorus was applied after fire to improve herbaceous growth and two years later the regenerating *Sarcopoterium spinosum* shrubs were controlled with selective herbicide. Subsequently, the vegetation in the treated areas was monitored for more than 20 consecutive years. The vegetation was undisturbed during the winter/spring growing season but was grazed during the dry summer of each year by beef cattle. In control plots, the shrubs returned to pre-fire dominance of shrubs within five years. With phosphorus and herbicide, shrub dominance was reduced by the vigorous herbaceous vegetation for more than 20 years. It is shown that appropriate management of grazing, periodic control of the shrub component, and occasional soil nutrient amelioration can lead to the development of attractive open woodland with a productive herbaceous understory. The practical feasibility of this management option depends on the relation between costs and benefits. Preliminary economic analysis indicated that management may be cost effective.

Keywords: Brush control, economic analysis, grazing, long term experiment, management options, phosphorus.

Introduction

Over the last half-century, both the vegetation and landscape of Mediterranean areas have undergone far-reaching changes. The removal of grazing has resulted in increases in shrub cover and biomass in these areas (Perevolotsky and Seligman 1998). In addition, the main objectives of land use of more marginal areas of lands in the northern countries of the Mediterranean Basin have shifted from subsistence agriculture and animal husbandry towards improvement of environmental and recreational values, conservation, and real-estate development (Rundel *et al.* 1998). Objectives of land management have changed from relatively well-defined production or subsistence aims to less well-defined environmental and ecological goals. Moderate grazing has been shown to contribute to floristic diversity (Noy-Meir *et al.* 1989) but also provide additional recreational opportunities by creating a more diverse landscape (Henkin *et al.* 2007). In many cases, densely wooded landscapes have created an attractive environmental setting - that also can become a serious fire hazard (Naveh 1975). However, when the landscape becomes dominated by spiny dwarf shrub thickets the biodiversity, forage and amenity values are reduced. Within these thickets it is desirable to promote a more herbaceous vegetation mosaic, ideally with greater heterogeneity at multiple scales with higher biodiversity, recreational and forage values. The value of these areas as pasture would be greatly increased if the early restoration, at the grassland stage, could be extended by reducing the rate of the successional shrub encroachment (Lasanta *et al.* 2006).

In the Mediterranean region, shrub encroachment usually follows abandonment of agricultural land or a reduction of grazing pressure (Pueyo and Beguería 2007). Secondary successional stages begin after fire with the formation of an open herbaceous layer (Callaway and Davis 1993) which is subsequently followed by shrub dominance (Zohary 1973). In Eastern Mediterranean batha communities on phosphorus-deficient terra-rossa soils, ephemeral grasslands that follow fires are overtaken within 5 to 10 years by successional dominance of shrubs (Henkin *et al.* 1999). These changes present a challenge to resource managers as there is little understanding of the effects of management interventions, the economic feasibility of the vegetation change and its relationship to management goals. Some of the vegetation types change slowly and persist for long periods especially when landscape management is constant. Protocols for management depend on the management objectives, and these can be realistic only if the rates of response to management intervention can be predicted with a fair degree of confidence.

We studied the rates at which vegetation cover changes under both natural undisturbed successional

processes and where the successional process was interrupted by management intervention (herbicides and fertilizer application or by wild-fire). Our study focused on the role of management and the dynamics of the woody and herbaceous components of the ecosystem. In particular we examined the financial feasibility of different treatment protocols on the basis of their Net Present Value (Henkin and Seligman 2011). The biological data were derived from a long term (20 year) experiment (Henkin *et al.* 2010) and the economic data based on a demonstration study that was implemented to test the practicality of the proposed management protocol (Henkin 2006). The ecological understanding derived from the study may be relevant to other Mediterranean regions where shrubby ecosystems dominate on P deficient soils.

Methods

The experiment was situated near Ein Ya'aqov, 15 km east of the Mediterranean coast, in the Western Galilee, Israel (long. 35°15'E; lat. 33°01'N; alt. 500 m). The climate is typical Mediterranean, with average annual precipitation of 806 mm, but with wide inter- and intra-seasonal variation. The vegetation is a typical Eastern Mediterranean batha shrubland, dominated by *Sarcopoterium spinosum* (L.) Spach dwarf shrubs (Zohary 1973) interspersed with patches of herbaceous species (mainly annuals). *Calicotome villosa*, a spiny, gorse-like shrub, often dominates vast areas. Trees, mainly *Quercus calliprinos* Webb., *Pistacia palaestina* Boiss., and *Crataegus aronia* (L.) DC are sparsely dispersed across the landscape.

This experiment was initiated during the winter of 1987/88. Monitoring of shrub cover and biomass production on patches between the shrubs began in the spring of that season, prior to the application of the treatments (Henkin *et al.* 1999). In the early summer of 1988, a wild-fire swept through the entire experimental area. The experimental treatments following the fire included four factorial combinations: P0H0, P0H1, P1H0 and P1H1, where P1 was an application of enriched (25% P_2O_5) superphosphate (4.5 g P/m) to the soil surface once, in the autumn of 1988; H1 was an application of herbicide (2,4-D, 57% acid equivalent in a 1.5% aqueous solution) to the regenerating *S. spinosum* shrubs in the spring of the second year after the fire. All treatments, including the control, were on 10 × 10 m plots set out at random in five replicated blocks. Sampling procedure included measurement of herbaceous biomass and the cover of the different vegetation components. The biomass and cover data were analyzed using a GLM model (SAS Institute 2002) that included fertilizer effects, herbicide effects and block effects, as well as interactions between the data. In addition, the long-term economic performance of the management protocol options were calculated from data derived from the 20-year experiment and from a case study that was implemented to determine the actual costs of the treatments.

Results

Shrub cover

The first stage of secondary succession, post-fire, was dominated by an open herbaceous formation (Fig. 1). In the control treatment, five years after the fire, a dense thicket of prickly burnet *Sarcopoterium spinosum* dominated the area, and 10 - 12 years after the fire the

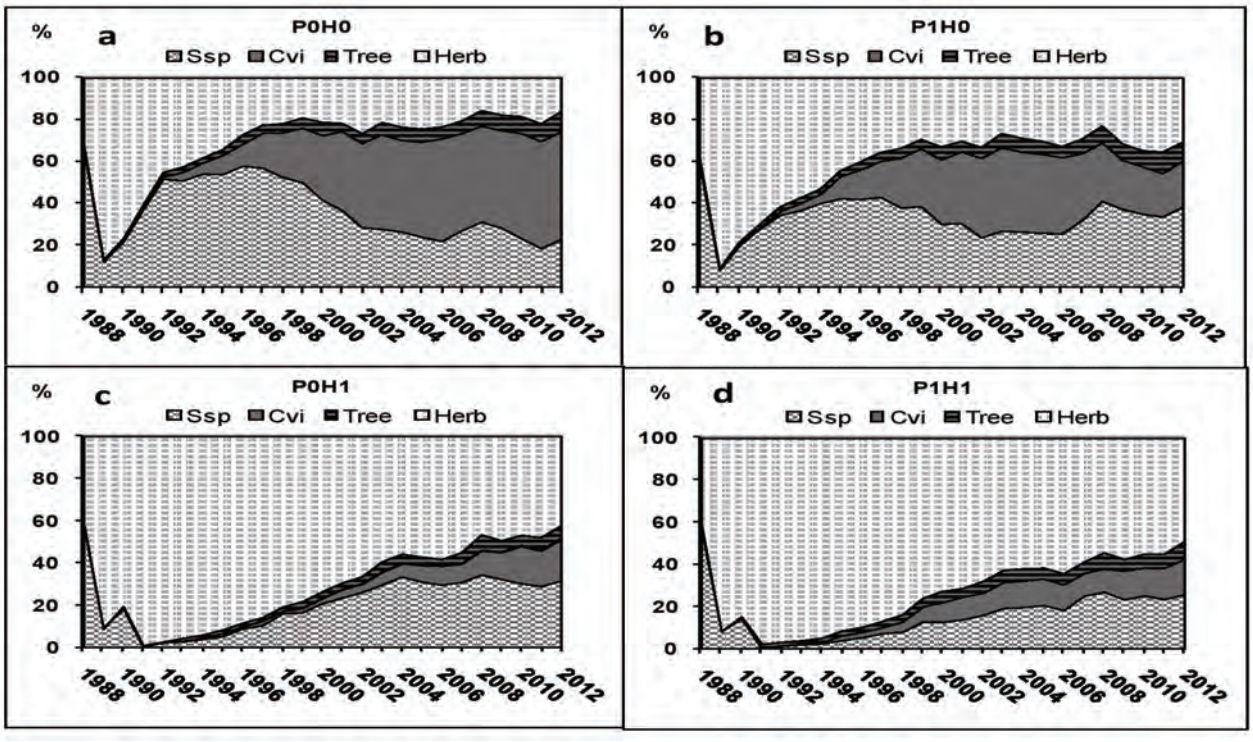

Figure 1. Effects of management treatments of super-phosphate (P0, P1) and herbicide (H0, H1) following fire on vegetation cover and composition [shrub (Ssp, *Sarcopoterium spinosum*; Cvi, *Calicotome villosa*) Tree and Herb (herbaceous vegetation)]

spiny gorse-like bush *Calicotome villosa* took over (Fig. 1a). Without herbicide, the shrub cover (*S. poterium* + *C. villosa*) reached an asymptote by the 10th year after the fire and by the 20th year, the shrubs covered 73% of the area.

Phosphorus (P) application alone increased the cover of herbaceous vegetation and maintained a slightly lower shrub cover that reached 58% of the area by the 20th year of the experiment (Fig. 1b). Herbicide alone had a highly significant effect on shrub regeneration ($P<0.0001$) that covered 48% of the area by the 20th year (Fig. 1c). The combined effect of both phosphorus and herbicide reduced the shrub cover further to 38% of the area by the 20th year (Fig.1d).

Herbaceous biomass and cover

In comparison with the control, phosphorus application at the beginning of the experiment increased the biomass production of the herbaceous patches throughout the 20 years of the experiment (Table 1); shrub control increased the cover of the herbaceous patches. The combined effect of phosphorus application and shrub control increased the 20-year average biomass production over the whole area of the plots by a factor of six. The treatment effect was highly significant ($P<0.0001$).

Economic analysis

The application of phosphorous for shrub control may be feasible if it is applied after a wild-fire and the treatment is applied to take advantage of the fire. In that scenario the income from the herd can cover the costs of the management treatment within six years. By the 15th year the net income is estimated to be four times higher than in the untreated control. If more intensive inputs of phosphorus and herbicide applications are necessary to maintain productivity the returns of the herd are lower, but still about three times higher than those of the control. By the 30th year, the differences were found to be even greater.

Discussion

The vegetation in the Mediterranean region has been heavily used for millennia by human communities and their livestock. It has developed a resilience that facilitates a rapid response to fire (and other disturbances) that often leads to spiny thicket formations after an ephemeral herbaceous grassland stage. The initial herbaceous dominance that is mentioned in other studies (*e.g.* Capitanio and Carcaillet 2008), in our case lasted for only a short time in a habitat with low soil P content.

Phosphorus amelioration alone maintained a long-term increase in the biomass production of herbaceous vegetation growing in the patches between the shrubs and even slightly reduced shrub dominance. Herbaceous dominance for a relatively longer period was achieved by herbicide application alone, while the combined effect of phosphorus application and shrub control (herbicide) retarded the regeneration of the shrubs even further: after 20 years, the ground cover of the regenerating shrubs was less than 40% compared to 73% in the control.

Table 1. Twenty-year average peak season biomass in herbaceous patches and average herbaceous cover with and without fertilizer application.

Treatments	No fertilizer	4.5 g P/m^2
	Peak biomass in herbaceous patches* (g DM/m^2, mean ± SD)	
No shrub control	131.0 ± 64.4	273.2 ± 90.8
With shrub control	231.5 ± 94.5	336.0 ± 122.9
	Percent herbaceous cover (mean ± SD)	
No shrub control	28.5 ± 15.8	36.4 ± 14.1
With shrub control	56.0 ± 15.1	62.1 ± 15.0

Conclusion

This experiment showed that under traditional management (beef herd production), a successional trend that leads to dominance of spiny thickets can be significantly delayed by herbicide and fertilizer application. In order to maintain the dominance of the herbaceous vegetation in the long-term, it may be necessary to repeat the treatments after 10 years following the initial application. The data showed that retardation of the successional trend is technically possible. Our economic analysis of the profitability this management scenario identified that under conditions under which such a management intervention can be practical economically. Since the use of uncultivated area for recreation and landscape improvement has become a common public interest, public financial support for grassland conversion should not be ruled out. In addition, the increased ecological services that are derived from more diverse grassland vegetation can justify public support, especially in areas of particular interest for recreation and tourism. We conclude that an appropriate management protocol to retard the successional process in a Mediterranean plant community can convert prickly shrub thickets into species-rich grassland communities with a much wider range of ecological services.

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