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Does soil seed bank diversity limit post-fire regeneration in small, fragmented, long-unburnt remnants of fire adapted vegetation?

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ABSTRACT

Soil collected from 38 sites on Kangaroo Island in South Australia, containing small remnants of senescent *Eucalyptus cneorifolia*-dominated mallee, was subject *ex situ* to both smoke aerosol and heat treatment to simulate burning. Further soil from a subset of 29 of the sites was left untreated as a control. A total of 113 native plant species and 50 introduced species germinated across all sites. Fifty-three of the native plant species that germinated were absent in the above-ground vegetation, including twelve rare or threatened species, and three species previously unrecorded from Kangaroo Island. Fourteen native species and six introduced species germinated in heat plus smoke treated soil but not in untreated soil from the same sites. Non-metric multidimensional scaling ordination indicated differences in native species composition between sites with a long history of sustained livestock grazing ("grazed" sites) and largely ungrazed sites ("ungrazed" sites). On average, significantly more native species germinated from treated soil sampled from "ungrazed" sites than were found in the standing vegetation, while for "grazed" sites this difference was not significant. This indicates the greater potential for post-fire regeneration of native vegetation from the soil seed bank of ungrazed sites than from that of long grazed sites. Both "ungrazed" and "grazed" sites contained weeds in their soil seed banks, including some species which were stimulated by heat plus smoke. This indicated that competition from weeds is potentially a problem when fire is used as a management tool to regenerate senescent understoreys.

1. Introduction

Increases in fire danger and unplanned fires are a likely consequence of climate warming in several regions of the globe, including southern Australia (Cary, 2002), necessitating an increased management response. Management or prescribed burning is an important and widely-applied tool used in the landscape-scale management of fire-prone ecosystems across the world, and as Penman et al. (2011) point out, management burning is commonly used to achieve two outcomes:- a reduction in fuel loads to mitigate the severity of unplanned wildfires ("fuel-reduction" burning), and a manipulation, protection or restoration of the status and composition of ecosystems ("ecological" burning). As the use of this management tool is likely to increase, it is important that we gain a better understanding of the consequences of management burning on the properties of ecosystems.

While high frequency management burning has been implicated in the decline of a number of plant species (Bradstock et al., 1997; Gill and Bradstock, 1995), the absence of fire can also result in reduced plant species diversity (Keith et al., 2002; Keith and Bradstock, 1994) due to processes such as competitive exclusion (Keith and Bradstock, 1994) and the need for fire for the recruitment of many understorey plant species (Auld and O'Connell, 1991; Keith et al., 2002; Orscheg and Enright, 2011). Management burning may be particularly useful for biodiversity conservation where clearance for agriculture has left scattered small remnants of native vegetation (Gill and Williams, 1996). In such agricultural landscapes, fires may no longer develop because of fire suppression and low fuel loads (Yates et al., 1994; Gill and Williams, 1996; Hobbs, 2003) and consequently plants in small remnants that rely on fire for recruitment may have few opportunities for regeneration (Yates and Ladd, 2005). Small remnants in heavily cleared agricultural landscapes are important since they often contain high concentrations of threatened plant communities (Davies, 1982, 1983, 1999) and plant species (Davies, 1986, 1992; Taylor, 2003). In their recent review of key research questions regarding the use of fire for biodiversity conservation, Driscoll et al. (2010) identified processes influencing the impact of fire regimes on biota as a major area requiring further study, and they

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also identified habitat loss and fragmentation as one of the three most important of such processes.

Effects of fire on vascular flora have been well documented in many forest communities in Australia (review in Gill and Catling (2002) and Vivian et al. (2008)) and elsewhere (e.g., USA; review in Keane et al. (2008)), and, to a lesser extent, in communities dominated by mallees (multi-stemmed *Eucalyptus* trees) in Australia (review in Bradstock and Cohn (2002), Bradstock et al. (2006) and Clarke et al. (2010)). However, fire research in Australia has largely centered on large, relatively unmodified areas of vegetation little affected by vegetation clearance or stock grazing, where large wildfires still occur relatively frequently. In such situations, burning has been found to increase the diversity of understorey plant species (Bradstock and Cohn, 2002) as long as fires are not too frequent. Conversely, there has been relatively little investigation of the effects of fire on small remnants in highly fragmented landscapes, where edge effects and surrounding land uses are important factors (Laurance, 2008). Where intensive, long-term grazing and fire exclusion have resulted in the loss of most plant species from the above-ground vegetation, regeneration of native vegetation communities is largely dependent on the survival of a healthy soil seed bank, and the ability of land managers to stimulate germination from this seed bank.

The current soil seed bank project aimed to establish a baseline set of data on the composition of soil seed banks at sites to be burnt as part of the Eastern Plain Fire Trial (EPFT), a large-scale fire ecology experiment being undertaken by the South Australian Department of Environment, Water and Natural Resources in conjunction with a large number of operational and research partners. The objective of the EPFT is to develop a better understanding of the role of fire for maintaining ecosystem diversity and health. It will involve conducting management burns at a variety of intensities in highly fragmented communities and measuring the *in situ* plant regeneration response.

The study presented here examines the pre-burn composition of the soil seed bank and the above-ground vegetation at each of the EPFT burn sites. It also investigates the response of the soil seed bank to the fire-related cues of heat and smoke in order to make some predictions about the likely response of the plant community to management burning events.

The following four key questions were addressed:-

(1) Does a diverse and germinable native soil seed bank remain in the small and highly fragmented remnants of senescent mallee vegetation?
(2) How does the plant species composition of the soil seed bank within small remnants of senescent mallee communities differ from that of the above-ground vegetation?
(3) How does past, sustained livestock grazing affect the diversity of the germinable soil seed bank?
(4) To what extent does the application of a simulated burning treatment stimulate the germination of seeds from the seed bank?

While extensive research has been undertaken into the effect of grazing on soil seed banks of rangelands (e.g., Bertiller, 1992; Kinloch and Friedel, 2005; Nichol et al., 2007; Kassahun et al., 2009) and grasslands (e.g., O'Connor and Pickett, 1992; Kratochwil et al., 2002; Márquez et al., 2002) around the world, the effects of grazing on the soil seed bank of small remnants of tree- or mallee-dominated vegetation surrounded by agricultural land is poorly known, despite such management practices being widespread in temperate regions around the world. Therefore, the results of the present study have broad application in the regeneration of small remnants of native vegetation in fragmented landscapes.

2. Material and methods

2.1. Site location and sampling

Kangaroos Island is Australia's second largest island after Tasmania and is situated off the coast of South Australia. It has a Mediterranean climate, with mean annual rainfall ranging from 500 to 900 mm (Burrows, 1979). The island consists predominantly of plains and plateaux infrequently incised by rivers and streams (Daily et al., 1979). Native vegetation over the majority of the island is dominated by mallees (multi-stemmed *Eucalyptus* trees) and has been extensively cleared for mixed wheat and sheep farming. In north-eastern Kangaroo Island, where the soil is most fertile (cracking clays and alkaline duplex soils; Northcote, 1979), only 16% of the original native vegetation remains following extensive clearance in the 1950s and 1960s (EPFT Working Group, 2008) despite this being one of the driest areas of the island. Remaining areas are mostly small and highly fragmented and have been isolated and not burnt for more than 30 years (Mowling and Barrett, 1981; EPFT Working Group, 2008). The area contains seven nationally threatened plant species (Davies, 1986, 1992, 1996; Bickerton and Davies, 2000; EPFT Working Group, 2008) and two threatened plant communities (*Eucalyptus cneorifolia–E. phenax* open-scrub and *Eucalyptus cneorifolia–E. rugosa* open-scrub over *Rhagodia candolleana*; Davies and Overton, 1998) which are potentially threatened in the longer term by fire exclusion. These communities are included in the Kangaroo Island Narrow-leaved Mallee (*Eucalyptus cneorifolia*) Eastern Plains Complex, a group of plant communities nominated for listing as nationally threatened ecological community under the Australian Government Environmental Protection and Biodiversity Conservation Act 1999 (Russell, 2009). It is of great conservation interest, therefore, to understand whether management burning can reverse the decline in species richness in these small remnants, as well as provide a management option that can be used for recovery of threatened plant species and communities at a landscape scale on Kangaroo Island and within comparable fragmented vegetation elsewhere.

Understanding soil seed banks is important since they are essential for seedling regeneration following fires and their composition may differ markedly from that of the above-ground vegetation. Data on the composition of both soil seed banks and above-ground vegetation were collected from 38 sites being studied as part of the EPFT (EPFT Working Group, 2008; Taylor, 2011a,b). All of these sites contained small patches (<5 ha) of native vegetation dominated by *Eucalyptus cneorifolia* (Kangaroo Island narrow-leaved mallee). At the time of the soil sampling and vegetation surveys, all sites had been unburnt for at least 20 years, some sites for over 70 years (S. Davidson pers. obs.; R. Davies pers. obs.). Twenty-four of these patches (sites) were isolated remnants in privately owned paddocks and had been accessible to sheep and/or cattle for at least 20 years (referred to as "grazed sites" hereafter). The remaining 14 sites ("ungrazed sites") were on fenced roadsides or quarry reserves, and therefore had not been exposed to prolonged periods of livestock grazing.

In each site, all plant species present in the above-ground vegetation were recorded from three $20 \times 20\ m^2$ plots. This sampling was undertaken both in autumn (early March 2009) and spring (late September 2009) to cover a greater range of flowering times for different species, and results were combined for each site.

Soil sampling was undertaken in early March 2009. Twenty $1 \times 1\ m^2$ quadrats were spaced at 2 m intervals around the perimeter of each above-ground vegetation sampling plot. Two 150 ml cores of soil (covering $30\ cm^2$ each) were extracted from within each of these quadrats. Only the top 5 cm of soil was collected since previous research (Auld and Denham, 2006; Auld and