USING FIRE SIMULATION TECHNIQUES TO ACHIEVE CONSERVATION AND RESTORATION OBJECTIVES

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Abstract
The aim of this project was to investigate the ability of artificially applied smoke and heat stimuli to simulate field responses of soil seed banks to fire. The ability to simulate field responses to fire would allow managers to better understand the effects that fire might have on a community before actually burning it. This knowledge is greatly lacking for many Australian ecosystems at present, such that fire is avoided as a management tool for fear of negative ecological impacts. The composition and density of seedlings was compared between soil samples subjected to fire in the field and soil samples treated with a range of heat and smoke stimuli in 4 different Australia ecosystems along a rainfall gradient from subtropical to arid. The treatments used were: no treatment; smoke for 1 hour; heat at 80°C; heat at 80°C and smoke for 1hour; heat at 105°C; heat at 105°C and smoke for 1 hour. The results vary greatly between ecosystems with no one treatment closely simulating the effects of fire. In addition, there was no significant difference between the control and the fire treatment in terms of the number of species or the abundance seedlings that emerged from the seed bank. Thus the role of fire and fire related cue in stimulating seed banks is discussed. The results also revealed a relationship between seed bank response and the likely "natural" fire frequency of an ecosystem which may be useful to identify optimal fire intervals when managing for biodiversity. However, this needs further investigation.

Introduction
Fire is an important evolutionary factor in many Australian ecosystems (Kemp 1981; Singh *et al*. 1981) however fire regimes have been drastically changed since European settlement with the near exclusion of fire in many places (Gill 1981). There is increasing recognition that fire is a useful management tool to prevent wildfires, manage specific plants such as endangered species and weeds, and promote biodiversity (Bond and van Wilgen 1996). The problem is that there is generally insufficient information to determine the most appropriate fire regimes (Tran and Wild 2000; Gill *et al*. 2002). In addition, experimenting with fire *in situ* is spatially and temporally consuming, and fire at inappropriate times, intensities and frequencies can have detrimental effects (Gill and Bradstock 2003). For reasons such as this, some conservation organizations advocate a precautionary principle approach to fire management.

Understanding the effect fire has on the soil seed bank is as important as understanding the influence of fire on the standing vegetation (Hill and French 2003). The soil seed bank provides a reserve of seeds capable of replenishing a community following the loss of mature plants (Thompson 1978; Bell 1999) and this is particularly valuable after a fire. Fire is vital in triggering and facilitating successful seed germination and seedling establishment (Whelan 1995) and many Australian plant species have become so adapted to fire that they will only geminate after fire (Bell 1999; Dixon *et al.* 1995). In Australia seeds of many species have seed dormancy overcome by fire, with the two main stimuli shown in laboratory tests to be heat and smoke (Enright *et al.* 1997; Read *et al.* 2000; Hill and French 2003).

The aim of this study is to determine the ability of artificially applied smoke and heat stimuli to simulate seed bank field responses to fire in a range of vegetation communities. The composition and density of seedlings which emerge from soil seed bank samples in a range of ecological communities after fire will be compared with glasshouse germination from soil samples treated with heat and smoke stimuli.

Materials and Methods
Study Sites
This study was undertaken in 4 different Queensland environments; an open mixed eucalypt forest community on Fraser Island (25 30 38.38S 153 07 48.46E) an open eucalypt woodland in south east Queensland's Pine Rivers Shire (27 18 20.69S 152 53 29.97E), a shrubby open woodland in a proposed scientific area approximately 30km north of Roma (26 14 32.87S 148 49 59.55E), and a tall open mulga shrubland on Currawinya National Park in south west Queensland (28 49 95S 144 29 09E). The characteristics of each study site are presented in Table 1.

Table 1. Characteristics of the study sites

Site Name	Vegetation Description	Rainfall (mm/yr)	Fire History	Date Sampled	Date Burnt
Fraser	Open mixed eucalypt forest with a scribbly gum and pink bloodwood overstorey and dense mixed understorey	1400	Frequently burnt, approx. every 5 yrs	15/04/02	09/08/02
Pine Rivers	Open eucalypt / *Casuarina* forest with a sparse midstorey of grass trees and a dense understorey of kangaroo grass and *Lomandra* spp.	1110	Unknown	06/08/02	10/08/02
Roma	Open eucalypt / *Callitris* woodland with a patchy midstorey of grass trees and a sparse grassy understorey	599	Wildfire in 1995	14/09/02	14/0902
Currawinya	Open mulga woodland with a low shrub stratum dominated by *Eremophila* spp and a sparse ground cover dominated by *Eragrostis* spp.	332	No evidence of fire, last fire at least 50 yrs ago	18/02/02	20/02/02

Sampling

In each of the 4 vegetation communities, two one hectare replicates were selected which were representative of the vegetation community, as homogeneous as possible, and at least 50 meters from roads, tracks, water points and other forms of disturbance. Ten plots were randomly selected in each replicate and a 1m radius circular quadrat was marked at each plot. The percentage cover of each species in each plot was recorded along with the percent cover of litter and bare ground. Six random soil samples (17cm x 9cm and 2.5cm deep) were collected from the eastern half of each plot. A soil sampling tool was designed and used to extract a block of soil that remained in tact as much as possible. Each sample was placed in an aluminium tray that was filled within 3cm of the trays lip with sterile sand (for drainage purposes). Trays were labelled and transported back to The University of Queensland, Gatton. This sampling technique allowed the seed bank samples to remain *in situ* rather than the more commonly used method of bulking the samples together in an attempt to simulate the actual conditions of the soil seed bank when it is burnt. This method has rarely been used. Only the top 2.5cm of topsoil was sampled as previous studies have shown that most of a seed bank is concentrated at the surface (Read *et al*. 2000). Following the fire, an additional sample was taken from the western side of each plot.

Treatments

The soil samples from each plot were randomly allocated a treatment;
Control – no treatment.
Smoke – smoke aerially applied for 1hr.
H1 – heated to 80°C for 1hr.
H1+S - heated to 80°C for 1 hour then smoke aerially applied for 1 hr.
H2 – heated to 105°C for 1 hr.
H2+S – heated to 105°C for 1 hr then smoke aerially applied for 1hr.
The sample collected after the fire was the “Fire” treatment.

The heat treatments were applied by placing the samples in a preheated oven for 60 minutes. This method of ‘dry’ heat was used rather than ‘wet’ heat as it is more like the actual conditions of a fire (Enright *et al.* 1997). The temperatures were chosen because heating at 80°C for 1 hr resulted in the top 1cm of soil reaching an average temperature of 60°C, while the 105°C heating allowed the soil to reach on average 80°C. These are considered to represent low and medium to high intensity fires respectively (Humphreys and Craig 1981). However, the extent to which seeds are heated within the soil seed bank depends upon their position within the soil, fire intensity and soil moisture (Enright *et al*. 1997; Auld *et al*. 2000).

The smoke treatment was applied aerially using a similar method to that of Dixon *et al.* (1995) and Read *et al.* (2000). The aerial application was used as it is a more effective form of smoke for germination than other methods such as smoke water (Lloyd *et al*. 2000). The samples were placed in a plastic tent into which cooled smoke was forced for 60 minutes. The smoke was produced in a drum from the slow combustion of dry and green foliage, cooled in a long pipe wrapped in wet hessian and forced into the tent. The dry foliage was leaf litter collected from the sites, while the green foliage was eucalypt and acacia branches collected locally.

Assessing Seed Banks

All soil samples were placed in the glasshouse directly after treatment. Positions were randomly rearranged twice weekly to decrease any effect of variation in the glasshouse. The samples were watered twice a day for five minutes

from an overhead irrigation system. Each seedling that emerged was recorded, identified to species level (where possible) and removed. If seedlings could not be identified, they were repotted and grown until identification was possible. The samples were observed for 12 weeks but few emerged after 10 weeks.

Data Analysis
In three of the sites the seedling abundance and species richness data required transformation to achieve normal distribution. The Currawinya site data was normally distributed, the Roma site data required log transformation and the Pine Rivers and Fraser sites required an arcsinh transformation. The seedling abundance and total number of species in each of the treatments was compared for the two replicates separately as well as for the entire site using one-way analysis of variance (ANOVA) with Tukey's honestly significant difference (HSD) *post hoc* comparison of means tests. Two-way ANOVA's were also used to test the independent influence of the artificially applied smoke and heat on the treatments. When a significance difference is reported, $P<0.05$.

Classification (agglomerative hierarchical fusion using flexible UPGMA) and ordination (SSH (semi-strong hybrid multidimensional scaling)) based on Bray-Curtis dissimilarities was undertaken using Patn (version 2.0, copyright 2001, CSIRO, L. Belbin and Griffith University). The classifications and ordinations were used to investigate the relationships between the treatments and sites in relation to the abundance of each of the species.

Results

Overall 9068 seedlings from 125 species emerged during the study. The number of seedlings varied greatly between vegetation communities ranging from 5063 in the Roma site to 254 in the Fraser site (Fig. 1a). There was less variation in the number of species between vegetation communities with a range between 24 and 37 (Fig. 1b).

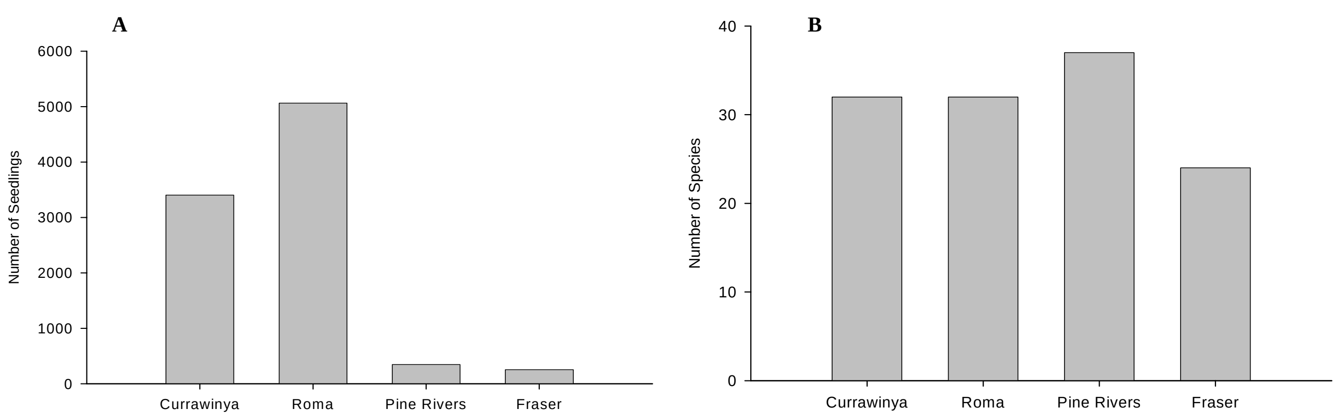

Figure 1. Total number of seedlings (A) and species (B) recorded in each site

The response to treatments varied between the different communities with no consistent pattern observed. The number of seedlings that emerged for each treatment in each of the communities is presented in Figure 2. There was no significant difference in the number of seedlings between treatments in the Roma or the Pine Rivers sites. There was a significant difference detected in the Fraser site between the Fire and the H2+S treatments only. In the Currawinya site there was a significant difference between the H2+S and two other treatments; Smoke and H1+S. The H2+S treatment yielded the most seedlings in all communities except the Roma site where it was second greatest.

The number of species recorded for each treatment in each site is presented in Figure 3. There was no significant difference in the number of species between treatments in the Currawinya, Roma or Pine Rivers sites. However, a significant difference was detected in the Fraser site between the H2+S treatment and all other treatments except both H2 and Smoke (Fig. 3). The H2+S treatment yielded the greatest number of species in the Fraser and Pine Rivers sites. Currawinya was the only site where the Control yielded more species than any of the treatments and the only site which had less species in the Fire treatment compared to the Control. But, the Fire treatment did not yield the most species in any of the communities. The proportion of species found in the Fire treatment but not in the Control was greatest in the Pine Rivers site (40%), then the Fraser site (36%), the Roma site (33%) and lastly the Currawinya site (12%).

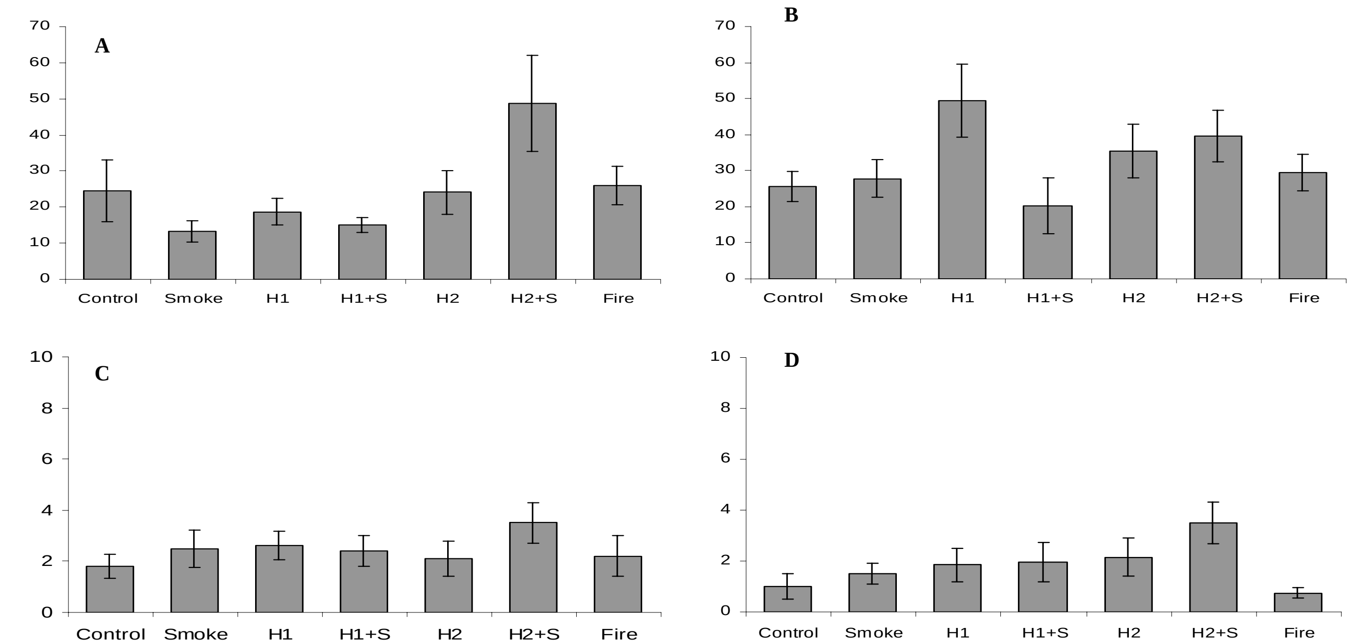

Figure 2. Mean number of seedlings (± SE) for each treatment in A) Currawinya, B) Roma, C) Pine Rivers and D) Fraser communities. Note a different Y axis scale in C&D.

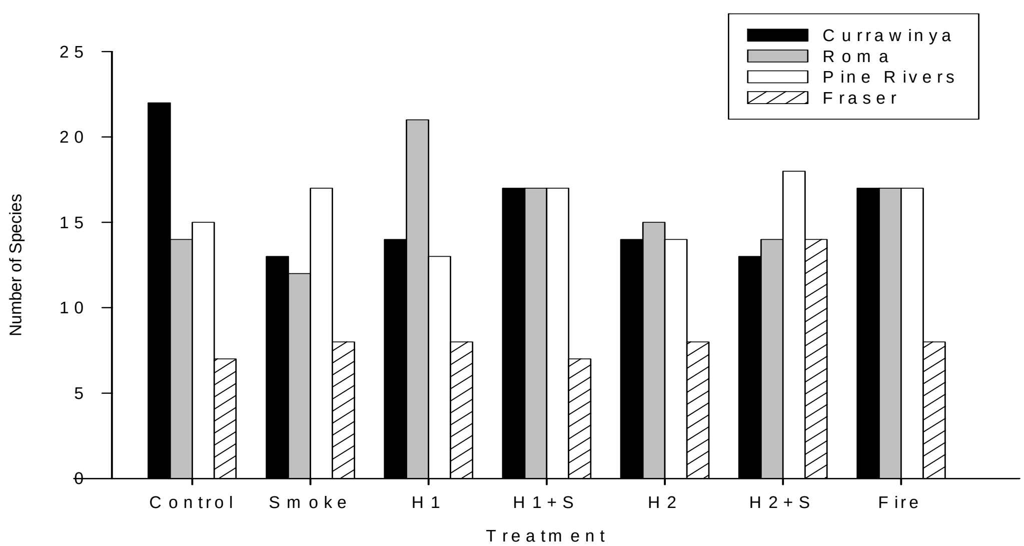

Figure 3: Total number of species for each treatment in each site.

There was a significant difference in both the number of seedlings and the number of species between the replicates in the Fraser community only. However, there was no significant difference between replicates within treatments in any of the communities based on either the number of seedlings or the number of species.

Ordination and classification of the species data revealed a distinct lack of clustering of the replicates within treatments and that no one treatment was closely associated with the fire treatment. In the Currawinya site Fire was closely related to H2+S and in the Roma site it was most closely related to the Smoke treatment. But in the other two communities it was the most or second most unrelated treatment. Similarly in some sites (Currawinya and Roma) the Fire and the Control treatments were closely related while in others they were the most unrelated.

Discussion

It has been reported there is an obvious role for a regime of fire in nearly all Australian vegetation communities (Good 1981; Cary *et al*. 2003) and there is mounting evidence of the high number of native species whose dormancy is broken, or germination improved, by the properties of fire (Dixon *et al*. 1995; Lloyd *et al*. 2000; Read *et al*. 2000). This study therefore assumed that fire would impact on the number and composition of seedlings that emerged from

the seed bank. But, the study revealed that there was no significant difference between the number of seedlings, or the number of species, that emerged from the soil seed bank after fire compared to the Control in any of the vegetation communities investigated. Though not significant, there was a pattern of more species in the Fire treatments compared to the Control in each vegetation community except Currawinya. Furthermore, there was a difference in the composition of the species that emerged from the Fire treatment in comparison to the Control.

There was no consistent pattern between communities in relation to the response to the different treatments. No treatment was consistently similar, or dissimilar for that matter, to the fire treatment. There are several reason that could explain this. Firstly it could be related to the methodology used in this study. The sampling effort may have been insufficient to detect the pattern. Soil seed banks are highly variable both temporally and spatially (Fenner 2000) and often high numbers of samples are required to accurately represent the soil seed bank (Page *et al*. 2006). Secondly, it is possible that the Fire treatment applied in this study was the wrong regime for these ecosystems. The burns could have been too low in intensity or too patchy to effect the seed bank evenly. The fact that the treatment with the highest temperature coupled with smoke (H2+S) yielded the highest number of seedlings in all communities (except Roma where it was the second highest) and was present each time a significant difference was detected between treatments, may attest to this theory. All of the burns conducted for this study were low in intensity for either safety reasons or because fuel loads were insufficient. A third reason could be that fire plays a different role in each of the communities investigated. For example, the fire treatment was closely related to the H2+S treatment in the Currawinya site and the Smoke treatment in the Roma site, two very different treatments. The composition of the species within each community was very different and thus may respond to, or be triggered by, different aspects of fire. A fourth reason may be that fire is not as important in these ecosystems as was assumed. Given there was no significant difference in either the number of seedlings or the number of species detected between the Control and the Fire treatments in any of the vegetation communities indicates that fire may not have a big impact on what emerges from the seed bank. Fire has many other effects on a community such as altering the structure of the vegetation, the composition and abundance of the standing vegetation, the soil chemical and physical properties, light availability and intensity, and removing allelopathic substances. We know that many Australian plants have adaptations that allow the standing vegetation to regenerate after fire and thus the impact on the soil seed bank may be insignificant in comparison. However, a number of unique species were detected with fire and this is important to consider.

A pattern was revealed which related to the longitudinal location of the sites studied. The number of seeds was greater in the more western sites (Roma and Currawinya) than the eastern sites, the dissimilarity between the species composition in the Fire and Control treatments increased as the location was more easterly, and the proportion of species found in the Fire treatment only increased as the location moved east. The annual average rainfall and its predicability also increases as the site location moves east. As the amount and predictability of rainfall changes so too does the type of vegetation, and thus the likely fire regimes. That is, in arid systems fire is likely to be infrequent and unpredictable while in higher rainfall areas fire is likely to be more frequent fires as biomass is accumulated more quickly, and more predictable with distinct wet/dry seasons. Fenner and Thompson (2005) state that seed banks are most advantageous in communities with frequent catastrophic disturbances that are unpredictable, and that the severity and predictability of the disturbance determines the persistence of a seed bank. Fire may be identified as such a disturbance and thus the seed bank should increase as fire (the disturbance) becomes more frequent. But as fire becomes more frequent, it also becomes more predictable. In these ecosystems it seems that the more predictable and frequent the fire regime is likely to be, the less reliant the community is on seed bank. It should also be noted that fire is not the only severe disturbances that impact on these ecosystems, the most obvious being drought in the arid and semi arid areas. So although the disturbance of fire is infrequent and unpredictable, the disturbance of drought is frequent, though still somewhat unpredictable. Considering this, Fenner and Thompson’s (2005) prediction of seed banks being more important in communities that have frequent but unpredictable, severe disturbance holds true with Currawinya and Roma having the highest seed bank records.

Although the number of seeds was higher in the sites with less frequent and unpredictable fire, the number of species that were found only in the Fire treatment increased as fire frequency increased. So although areas with infrequent and unpredictable fire regimes rely heavily on seed banks and thus had a much greater seed bank, the areas with more frequent and predictable fires had more species in the seed bank that were reliant on fire for germination. This is logical as why have seeds in the seed bank that need fire to trigger or enhance germination when fire is unlikely to be a frequent or predictable event. However, most plants are triggered to germinate by rainfall in arid systems (Inouye 1991) but rainfall is unpredictable and infrequent in these ecosystems so why have species triggered by rainfall when it

is infrequent and unpredictable? The difference is that moisture is a necessary resource for almost any plant to germinate where fire may be a factor that simply allows a competitive advantage. In the moister communities the canopy is denser and germination may be more reliant on a gap in the canopy than a rainfall event and fire can create such gaps. Thus having germination cues relating to fire may be extremely beneficial as it is more likely that gaps will be present post fire. Currawinya is the most arid site investigated in this study and it was the only site which had the highest number of species in the Control. This is a further indication that this is not a fire triggered system. Similarly Thomas *et al*. (2003) found that the germination of species from habitats that are infrequently burnt is not affected by heat shock or smoke.

Another explanation of this longitudinal pattern in the size of the seed bank is that fire depletes the seed bank and thus areas with more frequent fire are unlikely to have abundant seed banks. From our study sites, fire is the most frequent on Fraser Island with a fire occurring on average every 5 years. This could explain the low seed bank encountered on Fraser sites.

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