The influence of winter fire on seedling recruitment in a heathy woodland in south-eastern Australia

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PUBLICATION DATE

01-01-2023

HANDLE

10779/DRO/DU:27964941.v1

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Submitted in partial fulfilment of the degree of Bachelor of Science (Honours)

April 2023

Statement of responsibility

This thesis is submitted in accordance with the regulations of Deakin University in partial fulfilment of the requirements of the degree of Bachelor of Science (Honours). I, Teah Coate, hereby certify that the information presented in this thesis is the result of my own research, except where otherwise acknowledged or referenced, and that none of the material has been presented for any degree at another university or institution.

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Ethics

Department of Environment, Land, Water and Planning

Assessing plant functional diversity under varying climatic and burn regimes in the Anglesea heath

Dr Tricia Wevill

Permit number: 10009825

Abstract

Fire is an integral part of many Australian landscapes. Fire seasonality is specific for each landscape and burning out of the historic fire season may have long-lasting impacts on vegetation. Climate change is creating hotter and drier conditions in fire-prone landscapes in Australia, and they are becoming more susceptible to catastrophic fires. To combat risk to people and property, land managers conduct prescribed burns, typically in autumn, to reduce fuel loads and decrease the intensity of bushfires. However, the window of opportunity to safely conduct prescribed burns is narrowing, due to climate change. Therefore, conducting aseasonal burns in cooler and wetter months, is one potential option for land managers. We investigated the effects of winter prescribed burns on seedling germination in a heathy woodland in southeast Australia where bushfires have historically burnt in summer. We also examined the patchiness of winter burns to see if that enabled persistence of mature obligate seedling species. Vegetation and seedling surveys were conducted in spring 2022 at sites where prescribed burns were conducted in winter 2021. We found that these winter burns triggered germination for obligate seeding species, but some species were not present as seedlings and many species had a low abundance of seedlings. However, the patchiness of winter burns allowed for the persistence of mature obligate seeding species. Prescribed burns in winter could be used as an effective tool to decrease the amount of fuel in the landscape, however, the presence of some species in this landscape could decline as a result. Further research is required into burning out of season and its effects on germination.

Keywords: fire ecology, germination, fire season, winter, prescribed burning

FOR code: 3103 Ecology

Acknowledgements

Firstly, I would like to extend my sincerest gratitude to my supervisors Dr Tricia Wevill and Dr Anthony Rendall. I truly appreciate the constant pep talks and answers to my unending questions. Thank you for converting me into a fellow plant nerd and fostering my enthusiasm for research.

I would like to thank DEECA for the contribution which funded this project and made this research possible. Furthermore, I would like to extend my gratitude to Hamish Martin for consultation on the research questions and providing fire history mapping of the study region. I would also like to thank the Parks Victoria team in Anglesea for their guidance on the studied prescribed burns and walking us through the process.

I would also like to thank Michele Kohout and her team at the Arthur Rylah Institute for providing the Vital Attributes Database which was important for this research.

Next, I would like to extend my gratitude to the extensive number of volunteers who helped me complete my fieldwork. My sincerest gratitude to Mitch, Em, and Tara for teaching me plant ID on the job.

I would also like to send my wholehearted thanks to the eXtreme Plant Ecology Research team. I would not have been able to complete this research without the support of everyone. Specifically, I would like to thank Danny and Jerónimo for putting up with my antics.

Finally, I would like to thank Judd for encouraging me to send the scary but important emails.

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This thesis has been formatted to suit the International Journal of Wildland Fire.

List of abbreviations

ANOSIM – analysis of similarities

AS – average similarity

CAP – Canonical Analysis of Principal Coordinates

DEECA – Department of Energy, Environment and Climate Action

DELWP – Department of Environment, Land, Water and Planning

EVC – Ecological Vegetation Class

FS – facultative seeder

nMDS – non-metric multidimensional scaling

OR – obligate resprouter

OS – obligate seeder

PERMANOVA – Permutational Multivariate Analysis of Variance

PERMDISP – tests of homogeneity of dispersions

SIMPER – similarity percentage analysis

U – unknown response

1. Introduction

1.1 Fire and Australian flora

Fire is an integral part of many Australian ecosystems, and the landscape has evolved with fire over millennia (Singh *et al.* 1981; Bowman *et al.* 2011). It is a disturbance process that plays a significant role in shaping the structure of individual populations and the ecosystem they reside in, with adaptations in plants evolving at least 60 million years ago (Rundel *et al.* 2016). In many sclerophyllous vegetation communities in Australia, the suppression of indigenous burning practices post-colonisation has led to an increase in vegetation density and consequently, the frequency and intensity of bushfires (Adeleye *et al.* 2022). Furthermore, anthropogenic climate change is creating hotter, drier conditions which is increasing the opportunities for more intense fires to occur in Australia (Clarke *et al.* 2013a). The average temperature of Australia has been increasing every decade and average rainfall has been decreasing in south-east Australia. (Head *et al.* 2014). Hotter conditions and less rainfall create drier fuel (including live plant materials) which creates conditions for more intense fires (Matthews *et al.* 2012; Andres *et al.* 2022). More fuel also creates fuel continuity which encourages bushfires to spread more rapidly and at dangerous rates (Gould *et al.* 2007). Climate change is creating differences in seasonal weather patterns which, consequently, is influencing the vegetation responses to fire (Bradstock 2010; Bradstock *et al.* 2020; Nolan *et al.* 2020).

Plants have evolved many adaptations to cope with fire as a disturbance. Plants have been classified into functional groups that describes the strategy a species uses so the population can persist in fire-prone landscapes (Pausas and Keeley 2014). Obligate seeding species do not possess mechanisms to protect the individual plant. Obligate seeders reproductive strategy is to allow the mature individuals to be killed by fire but heat or smoke from the fire triggers germination of a soil or canopy stored seedbank (Pausas and Keeley 2014). Obligate resprouting species utilise the strategy of resprouting after a fire. Part of the individual is burnt, either the protective outer layer of bark on a trunk or the above-ground section of the plant, and the protected meristematic tissue in the trunk or the soil is capable of resprouting after the fire so the individual can continue living (Marais *et al.* 2014). Obligate resprouters are still capable of seedling recruitment during inter-fire periods, but the seedbank is not triggered to germinate as a post-fire response (Pausas and Keeley 2014). Facultative seeders are species capable of using both resprouting and seeding mechanisms as a post-fire persistence strategy (Keeley *et al.* 2006). This strategy is advantageous as post-fire conditions are not always optimal for successful recruitment and so ensuring the species has another survival strategy increases the chances for the persistence of the population (Pausas and Keeley 2014).

Seed dormancy is an adaptation that benefits plants by increasing the chances of germination and survival (Ooi *et al.* 2004). The seeds remain in a non-germinating state until conditions are optimal for the survival of any potential germinants (Baskin and Baskin 2001). After a fire consumes the leaf litter and understorey of a landscape, empty space is created that allows for seedlings to get access to more resources, such as light (Bond and Van Wilgen 1996), and decreases the competition for resources between seedlings and mature vegetation (Keith 2017). The burnt material from a fire puts nutrients back into the soil (Raison 1980). These conditions are ideal for germinants as they increase the chances of the survival, hence, dormancy processes ensure that seeds are capable of being stored in the seedbank until viable conditions are met. Physical dormancy prevents the seed from germinating by possessing a barrier that stops water from permeating the seed (Pausas and

Lamont 2022). Serotinous species utilise physical dormancy, as the species possess canopy-stored seed in hard, woody capsules that requires the heat from fire to crack open the capsules (Cowling and Lamont 1985; Lamont 1991; Keeley *et al.* 2011). This allows the seed to drop to the ground and begin germination if sufficient soil-water is available. Physiological dormancy is regulated by mechanisms that prevent the seed from maturing (Pausas and Lamont 2022). Dormancy is broken when the seed receives the required chemical cues, such as the chemicals in smoke (Dixon *et al.* 1995), or a change in the external environment, such as warm/cold stratification (Baskin and Baskin 2001). Once dormancy is broken, the seeds can continue to mature. After maturation, the seeds may begin to take in water and start germinating or die if environmental conditions are not suitable. If the necessary cues do not reach the seedbank, the seeds will stay in the dormant state until the cues appear, or the seeds senesce (Ooi 2010).

1.2 Fire regime

A fire regime describes the frequency, intensity, severity, size, and seasonality of the fires that occur in a particular area (Murphy *et al.* 2013; Miller *et al.* 2019). Plant communities are adapted to different regimes dependent on the attributes of the plants within the community. These attributes include lifespan, time to reproductive maturity, and longevity of the seedbank (Cheal 2010). The tolerable fire interval for a community is determined by the time for obligate seeding plants to reach reproductive maturity and contribute seeds to the seedbank. If a burn occurs before the minimum tolerable fire interval, species are not able to contribute to the seedbank and will deplete the number of individuals in the population (Bradstock *et al.* 1998a; Cheal 2010). Alternatively, the maximum tolerable fire interval is how long it takes before the sexually mature individuals senesce and the seedbank becomes non-viable. If burns occur outside of the tolerable fire interval over a long-term period, the species population can become locally extinct (Cheal 2010).

1.2.1 Fire intensity

Plants require a specific threshold of soil temperature to break seed dormancy and trigger germination (Auld and O'Connell 1991; Santana *et al.* 2010). The intensity of a fire above-ground influences the temperature the soil reaches. Bushfire intensity can range from low to high depending on the time of year, fuel moisture, and fuel levels (Bradstock *et al.* 1998b). Prescribed burns are usually of lower intensity due to the controlled nature of the burns (Penman *et al.* 2007). Intensity is also influenced by seasonality. A hot and dry season creates conditions for higher intensity burns, whereas a burn during cool, wetter months has a lower intensity (Grant *et al.* 1997). This is due to the quantity and dryness of fuel. The drier the landscape, the more fuel is created through the shedding of leaves and bark. The intensity of a burn can also influence the patchiness of a burn, as hotter flames can burn the thicker fuel and continue spreading, whereas a less intense fire will only be able to burn finer fuel and will allow for more mature vegetation to be left in the landscape (Gould *et al.* 2007). Low intensity fires do not trigger adequate germination for some species (Auld and O'Connell 1991), and there is an increase in competition for space, light, and nutrients between emerging seedlings and mature vegetation (Keith 2017). Higher fire intensity can increase post-fire recruitment (Knox and Clarke 2006; Palmer *et al.* 2018). However, if the fire is too intense, it can potentially kill seeds in the soil seedbank and canopy stored seed (Cury *et al.* 2020).

1.2.2 Frequency

The frequency of the fire regime refers to how often a fire occurs in the same area. Regions and ecosystems have different requirements for the frequency of fires to occur (Bowman *et al.* 2014). This is determined by the requirements of the plants. Obligate seeders are susceptible to fire frequency changes (Myerscough and Clarke 2007) as the plants require two to five years to become sexually mature and a further six years after maturity is reached to maximise contribution to the seedbank (Auld 1987; Ooi *et al.* 2006b). If frequently repeated fires continuously kill the individuals of an obligate seeding species before reaching sexual maturity, the population in that region will not be able to sustain itself (Bowman *et al.* 2016). In the short-term, obligate resprouters benefit from frequent fires, as the individuals have capacity to dominate an area after fire, whereas obligate seeders can take years before reaching the pre-fire abundance levels. However, the lignotubers in the soil of obligate resprouters have a limited capacity to resprout after a disturbance before the individual can no longer resprout (Moreira *et al.* 2012; Clarke *et al.* 2013b). Therefore, in the long-term, fires that are more frequent than the required regime specifies will cause a shift in the vegetation composition.

1.2.3 Season of burn

Each ecosystem has a specific fire season that fits within the regime, usually during or after the hottest and driest time of year. If a fire occurs outside of the historic fire season, post-fire recruitment can decrease (Tangney *et al.* 2022), and any seedlings that do germinate can grow at a slower rate which affects the chances of seedling survival (Ooi 2010; Miller *et al.* 2021). Seasonality affects fire intensity due to differing fuel moisture levels. Burns after a dry summer season are expected to be more intense as the fuel moisture content is low and, therefore, more flammable (Grant *et al.* 1997). Season is linked to delayed emergence processes in plants. In an ecosystem that has seasonal winter-rainfall and hot, dry summers, seeds have capacity to delay the germination process until optimal conditions are met (Ooi *et al.* 2004). These conditions can include soil moisture levels, optimal range of temperature, or specific day length. Ooi (2010) found that Ericaceous species delayed germination up to 15 months after fires outside of the historical fire season due to seasonal germination cues (Ooi *et al.* 2006a; Ooi 2010).

1.3 Fire management strategies

Prescribed burning is a management tool used by land managers to reduce the risk of bushfires (Morgan *et al.* 2020). As climate change increases the risk of more intense bushfires, prescribed burning has the primary aim of reducing risk to lives and assets (Fernandes and Botelho 2003). Prescribed burns work by decreasing the amount of fuel in the landscape around areas of human populations before the fire season, hence, decreasing the intensity of unplanned fires (Bradstock *et al.* 1998b; Gibbons *et al.* 2012). These burns are conducted usually in spring or autumn. Optimal conditions are required to conduct a prescribed burn safely, as the burn cannot take place if conditions are too hot or windy (Duff *et al.* 2019). This narrow window of opportunity is decreasing as climate change creates hotter, drier conditions throughout the year (Di Virgilio *et al.* 2020). As a response, land managers are considering conducting prescribed burns in the cooler, wetter months. In dry sclerophyll forests, Penman and Towerton (2008) concluded that conducting prescribed burns during autumn did not allow for soil temperatures to reach the required threshold to trigger germination. Therefore, conducting prescribed burns during the wettest season of the year may not trigger sufficient germination to maintain populations.

Mosaic burning is a large-scale prescribed burning strategy used to create heterogeneity across the landscape (Duncan *et al.* 2015). By burning different large areas using different fire interval periods (Burrows *et al.* 2021), this intentional strategy allows for diverse combinations of maturity stages so that sexually mature individuals can still contribute to the seedbank whilst simultaneously allowing for new seedlings to germinate (Penman *et al.* 2007). This large-scale mosaic is different to the patchiness often created from a prescribed burn. Not all of the area will burn due to multiple factors including fuel discontinuity, landscape factors (rockiness), and differing soil moisture across the landscape (Duncan *et al.* 2015). This is especially true for burns that occur during seasons of high moisture levels (Oliveira *et al.* 2015). The fine-scale patchiness that is created within a burn unit can also allow for the persistence of mature individuals and the opportunity for germination (Penman *et al.* 2007; Burrows *et al.* 2021).

1.4 Significance of Anglesea region

The Anglesea heathlands is the most floristically diverse area in Victoria. The region contains 31% of the orchid species found in the state (Carr 2017), with many of these species being endemic to the heathlands. The Anglesea township is located in close proximity to the surrounding heathlands, deeming it a high-risk area for fire. In 1983, the Ash Wednesday bushfires devastated the Anglesea area with lives and property being lost (Krusel and Petris 1992). Since then, prescribed burning has been conducted in the heathlands with the primary aim of protecting lives and assets in the town (Department of Environment Land Water and Planning 2016). 40 years of prescribed burns across the landscape has created a unique heterogeneity of stand ages.

The historical fire frequency for the heathy woodlands is every 15 to 40 years during the dry season of late summer (Cheal 2010). Prescribed burns in this region are usually conducted in spring and autumn (Department of Environment Land Water and Planning 2016), when fires are easier to control (Penman and Towerton 2008). However, land managers are interested in conducting prescribed burns during winter as the wetter conditions make it a safer time of year to conduct the burns. A heathy woodland system in a Mediterranean climate, with hot, dry summers and cool, wet winters, is adapted to burn in late summer when the fuel loads are driest. The fire promotes germination of seedlings in autumn and winter. Germination and growth therefore occurs during the highest rainfall period of the year, allowing the seedlings to develop adequate root systems to survive the following summer, or the lowest rainfall period (Potts *et al.* 2010). Prescribed burning in this region has been deemed necessary for the safety of the town, but there is little knowledge on the effects of the vegetation community. The burns may not reach a high enough intensity to trigger germination, however, heathland systems usually burn at a high intensity due to fine fuel size (Keith 2017), therefore, winter burns may also burn at a high intensity regardless of the fuel moisture content in this landscape.

1.5 Aims

If climate change is driving land managers to burn out of the historic fire season, it is imperative to understand the impacts on seedling recruitment in the Anglesea heathy woodlands. It is also important to understand if an increase in patchiness enables some mature individuals to persist and, therefore, be present in a landscape that is being burnt more frequently than the minimum tolerable interval.

The two primary aims of this research are:

1. Determine whether winter burns promote a germination response from obligate seeding species.
2. Determine if patchy winter burns facilitate a fine-scale fire mosaic across the landscape whereby mature obligate seeding species persist.

2. Methodology

2.1 Study region

This study was conducted within the Anglesea Heathlands (38°38’S, 144°14’E), located in the Great Otway National Park, two hours southwest of Melbourne, Victoria. Survey sites were in areas classified as heathy woodland EVC 48 (Department of Sustainability and Environment 2004), which is characterised by a low, sparse canopy of *Eucalyptus* spp., a dense layer of sclerophyllous shrubs (Keith 2017) and oligotrophic soil. The heathlands have a Mediterranean climate with winter-dominated rainfall and dry summers (Keith 2017). The average minimum and maximum temperatures in summer and winter are 13.7°C/22.6°C and 7.6°C/13.9°C respectively. Mean annual rainfall is 631mm (Bureau of Meteorology 2023). Fire history of the area is well mapped and known. This information, and in consultation with local Parks Victoria staff, was used to select three sites that had burned in winter 2021. Each site had some topographic and burn history differences. However, the primary objective of this research was to determine whether prescribed burning in winter was effective in triggering germination. Hence, sites were selected using stratified random sampling to ensure equal sampling units at each site; this also enabled site differences to be accounted for in the statistical analyses. Each site had sections that were classified as burnt, patchy and unburnt. We therefore stratified each site to include an equal number of quadrats in each treatment class. This resulted in eight replicate quadrats in each treatment for a total of 24 quadrats per site and 72 quadrats in total (Figure 1). Burnt quadrats were burnt across the entire quadrat with no remaining living shrubs. Patchily burnt quadrats were partially burnt and the fire created a fine-scale mosaic that allowed for some shrub species to survive. Unburnt quadrats were selected in areas from DEECA fire units that were prescribed burnt but the area did not experience any fire.

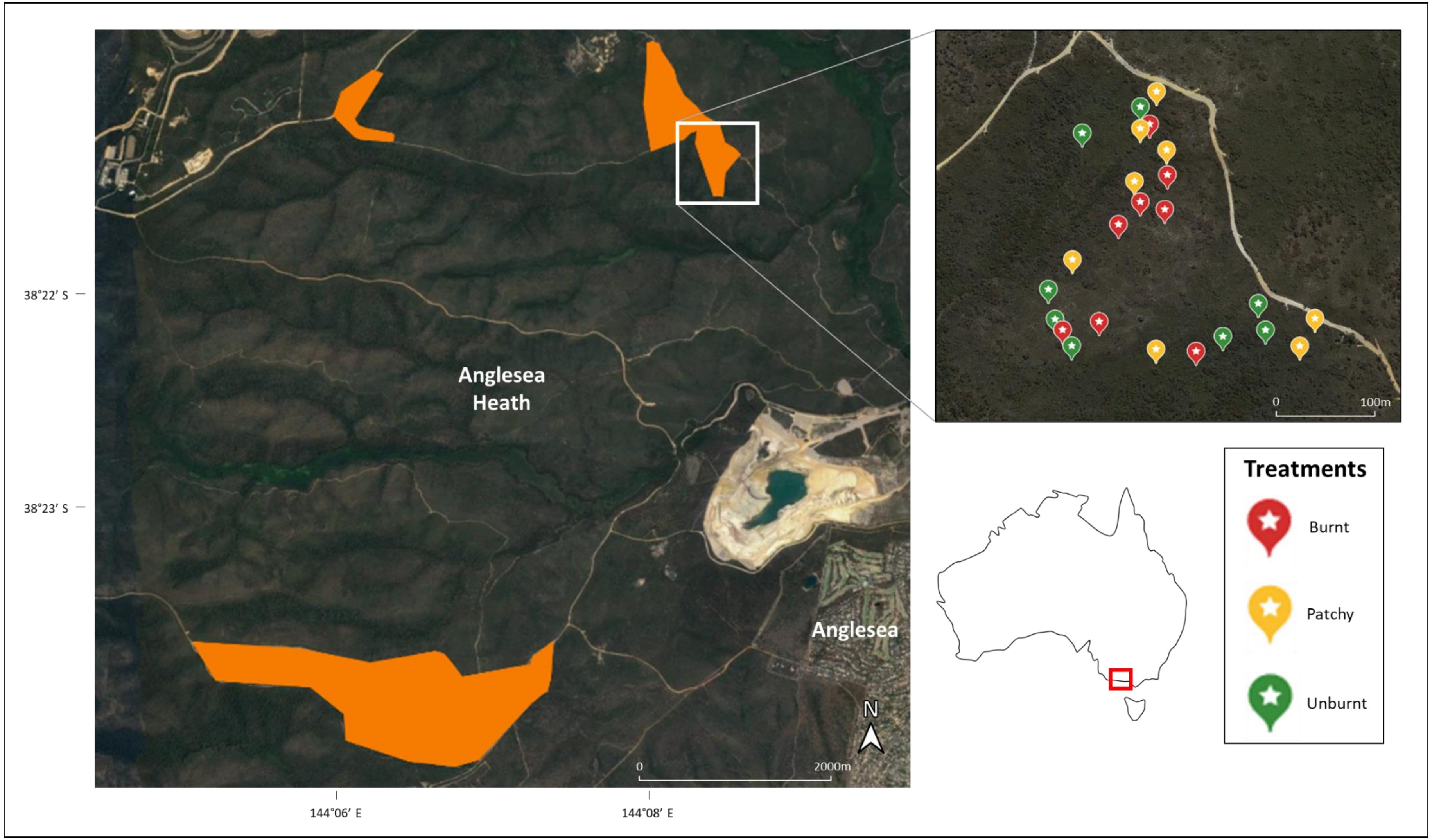


Figure 1: Map of the Anglesea Heath (Google Earth 2023) showing quadrat locations in three winter 2021 burn units. Treatment of quadrats are indicated by red (burnt), yellow (patchy), and green (unburnt) points.

2.2 Sampling

Previous studies have determined that a 10m x 10m quadrat is the optimal size for vegetation surveys in the Anglesea heathy woodlands (Radalj 2018). Within each quadrat, all vascular plant species presence and percentage cover was recorded. Percentage cover was recorded estimating the cover of species in metres squared. A single individual of a species was recorded as 0.01%. With two or more individuals present, the total cover was tallied in 0.1% increments. All plants were identified to species level where possible, or to genus level for plants that did not have all spotting characteristics present e.g. orchid species that were just about to flower but not all flowering parts could be observed. Identification was aided with the assistance of field guides and expert knowledge when out in the field. For any plants that could not be identified in the field, samples were collected and keyed out later using the Flora of Victoria (VicFlora 2023) with the assistance of botanical experts. All plants were classified into functional groups using the DELWP Vital Attributes Database (Arthur Rylah Institute 2015): obligate seeders (OS), obligate resprouters (OR), facultative seeders (FS), and unknown response (U). These classifications are based on observations in the field, from previous research, and from different types of ecosystems. In instances where a different functional response was observed, this response was used in our classification and the data reported to the Vital Attributes Database. The scorch height (in meters from the base) of all trees in a quadrat to a maximum of five were measured to estimate fire severity. To determine the richness and abundance of seedling germination, ten plots of 1m x 1m were established within each of the 72 quadrats, for a total of 720 plots (Figure 2). The plot size of 1m x 1m was determined using a species area curve (Cain 1938). Within each plot, every seedling was counted and identified to species level; if not enough spotting characteristics could be observed genus level was recorded.

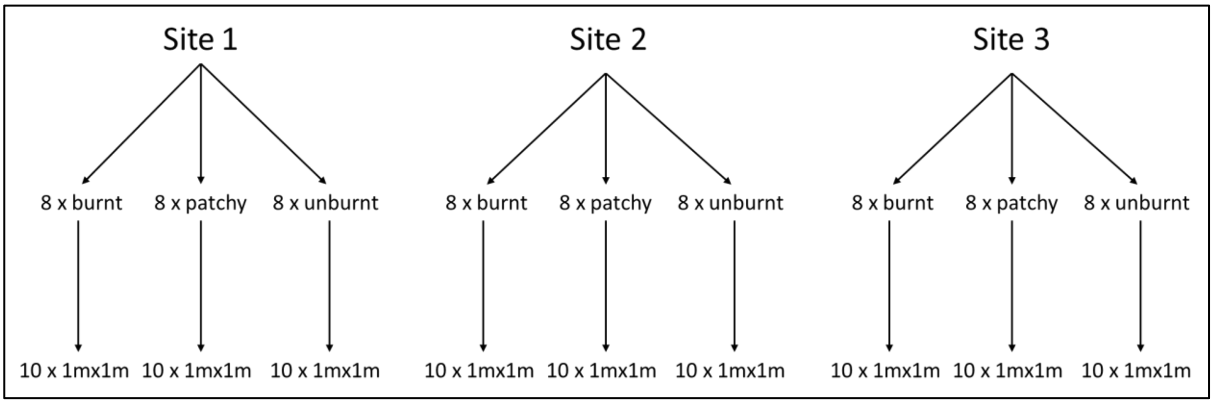


Figure 2: Diagram displaying the number of 10m x 10m quadrats per treatment per site and the number of 1m x 1m plots per quadrat per site. The treatments include burnt, patchy and unburnt.

2.3 Statistical analyses

Statistical analyses were completed using R v4.1.0 (R Core Team 2022) and PRIMER v7 (Clarke and Gorley 2015). VicFlora (2023) was used to classify species into lifeforms (trees/shrubs, grasses/sedges/rushes, herbs, twiners). The Vital Attributes database was used to classify species into functional groups (Arthur Rylah Institute 2015).

To look at differences in seedling composition across treatments and mature functional group richness across treatments, we used Permutational Multivariate Analysis of Variances (PERMANOVA) in PRIMER v7. Bray-Curtis similarity matrices were created with a dummy variable of 1 included to account for completely unique non-overlapping site-level assemblages. PERMANOVAs included treatment as a fixed effect, with plot nested within site included as a random effect to account for pseudo-replication. Seedling PERMANOVAs were run using Type I sums of squares and mature vegetation PERMANOVAs were run using Type III sums of squares. All PERMANOVAs were run with 9999 permutations. If PERMANOVAs suggested differences, pairwise comparisons were run to detect any differences between treatments. Any differences found with a PERMANOVA can either be due to differences in composition across the treatments, differences in treatment dispersion, or a combination of both. To check for compositional differences, a non-Metric Multidimensional Scaling (nMDS) plot with 100 restarts was created to visualise the compositional dissimilarity across treatments. To confirm if differences could be attributed to dispersion, tests of homogeneity of dispersions (PERMDISP) were run with 9999 permutations and treatment as the group factor. If differences in composition were found, a Canonical Analysis of Principle Coordinates (CAP) was used to identify which species were the greatest influence on differences.

Generalised Linear Mixed Models were used to determine differences in seedling abundance and seedling functional group richness across treatments. Models included treatment as a fixed factor. Site and quadrat were included as random factors, with quadrat nested in site, to account for pseudo-replication. Both obligate seeders and facultative seeders were modelled with Poisson distributions. Overdispersion was checked to confirm that Poisson models were appropriate. Residual values were plotted against fitted values, and against each variable in the models, to ensure distributional assumptions were met. Cook distance plots were used to assess the models for influential outliers.

To explore seedling and mature vegetation compositional differences across treatments, and differences in mature species cover across treatments, seedling and mature vegetation data were transformed to presence/absence. Seedling plots were pooled to quadrat level. Separate resemblance matrices using Euclidean distance were created to compare similarity between ages (seedling and mature) across the three treatments. A Bray-Curtis similarity matrix was created for mature species cover. NMDS plots with 100 restarts were created to visualise the dissimilarity between seedling and mature composition. One-way crossed

Analysis of Similarities (ANOSIM) tests with 9999 permutations were run to confirm any differences between composition. Similarity Percentage (SIMPER) analyses were conducted to determine the species that were contributing the most to dissimilarity between seedling and mature composition.

3. Results

3.1 Data overview

Vegetation surveys identified 135 unique species from 95 genera and 39 families. The number of species found across all quadrats ranged from 21 to 62. A total of 29 species could not be identified to genus level and were labelled as unknown. A total of 30 obligate seeders (OS), 29 obligate resprouters (OR), 52 facultative seeders (FS), and 61 unknown (U) responses were identified. Seedling surveys across all study sites tallied 13,241 seedlings in total. 60% of seedlings identified were trees/shrubs, 5% were grasses/sedges/rushes, and 34% were herbs.

3.2 Effect of fire on seedling abundance and composition

I found a difference in seedling abundance across treatments, with unburnt quadrats having a lower number of seedlings compared to patchy and burnt (Z=-11.31, df=2,714, p<0.001). Patchy quadrats trended to having a lower number of seedlings compared to burnt quadrats (Z=-1.82, df=2,714, p=0.069) (Figure 3). I found a difference in seedling composition across burn treatments (pseudo-F=18.884, df=2,719, p<0.001). Patchy and burnt had the highest similarity across quadrats (average similarity [AS]=25.813), followed by patchy and unburnt quadrats (AS=19.58), and unburnt and burnt quadrats were the least similar (AS=13.867). The nMDS plot (stress=0.22) showed overlapping of treatments, indicating similar seedling composition across treatments. Unburnt quadrats were tightly clustered compared to patchy and burnt (Figure 4). This was confirmed from the PERMDISP (F=29.702, df=2,717, p<0.001), with unburnt quadrats being the least dispersed (μ=46.682), followed by burnt (μ=50.779), whereas patchy quadrats were highly dispersed (μ=53.398). Exploring the CAP analysis confirmed the compositional differences between treatments. Burnt quadrats were associated with more *Xanthoisa hueglii*, *Laxmannia orientalis* (herbs) and *Leucopogon glacialis* (shrub) seedlings, while patchy quadrats contained more *Leptospermum* sp. (shrub) and *Platysace heterophylla var. heterophylla* (herb) (Figure 5).

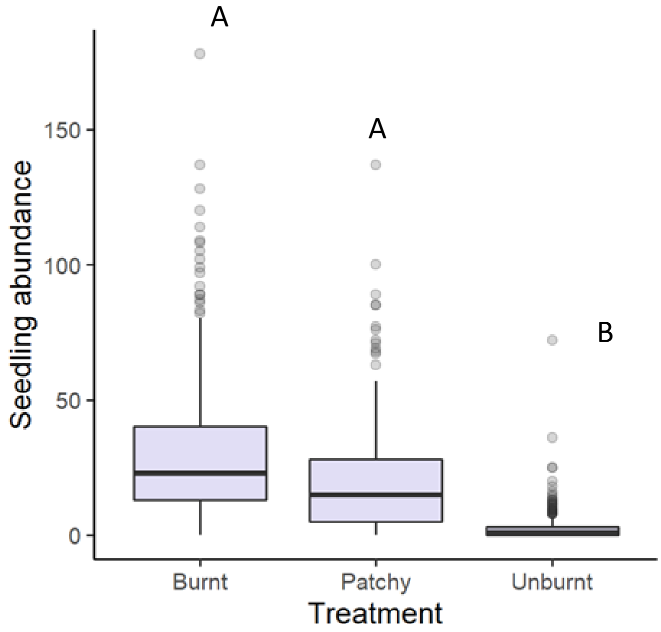


Figure 3: Seedling abundance across each burn treatment. Different uppercase letters denote statistically significant differences (p<0.05). Shared letters denote no difference.

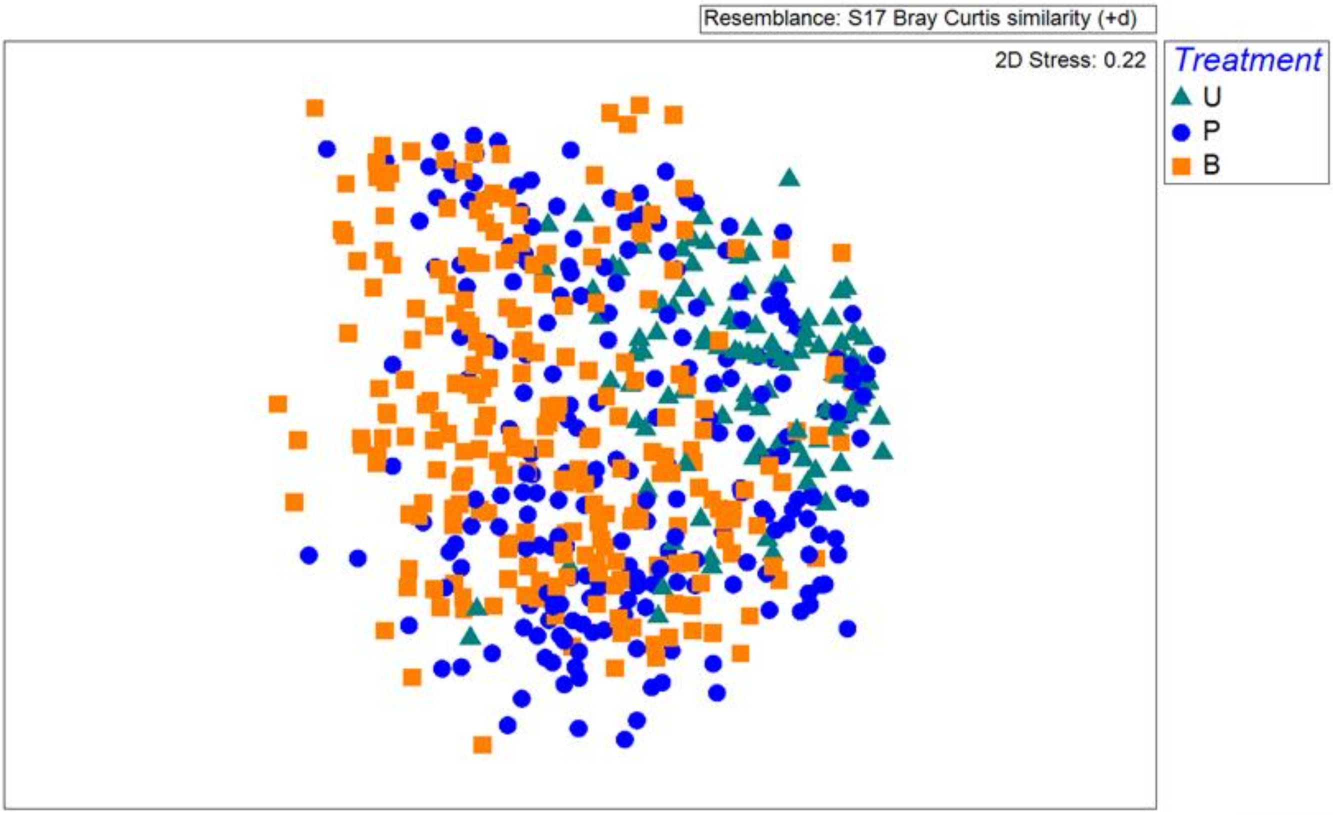


Figure 4: Non-metric multidimensional plot visualising differences in seedling composition across treatments.

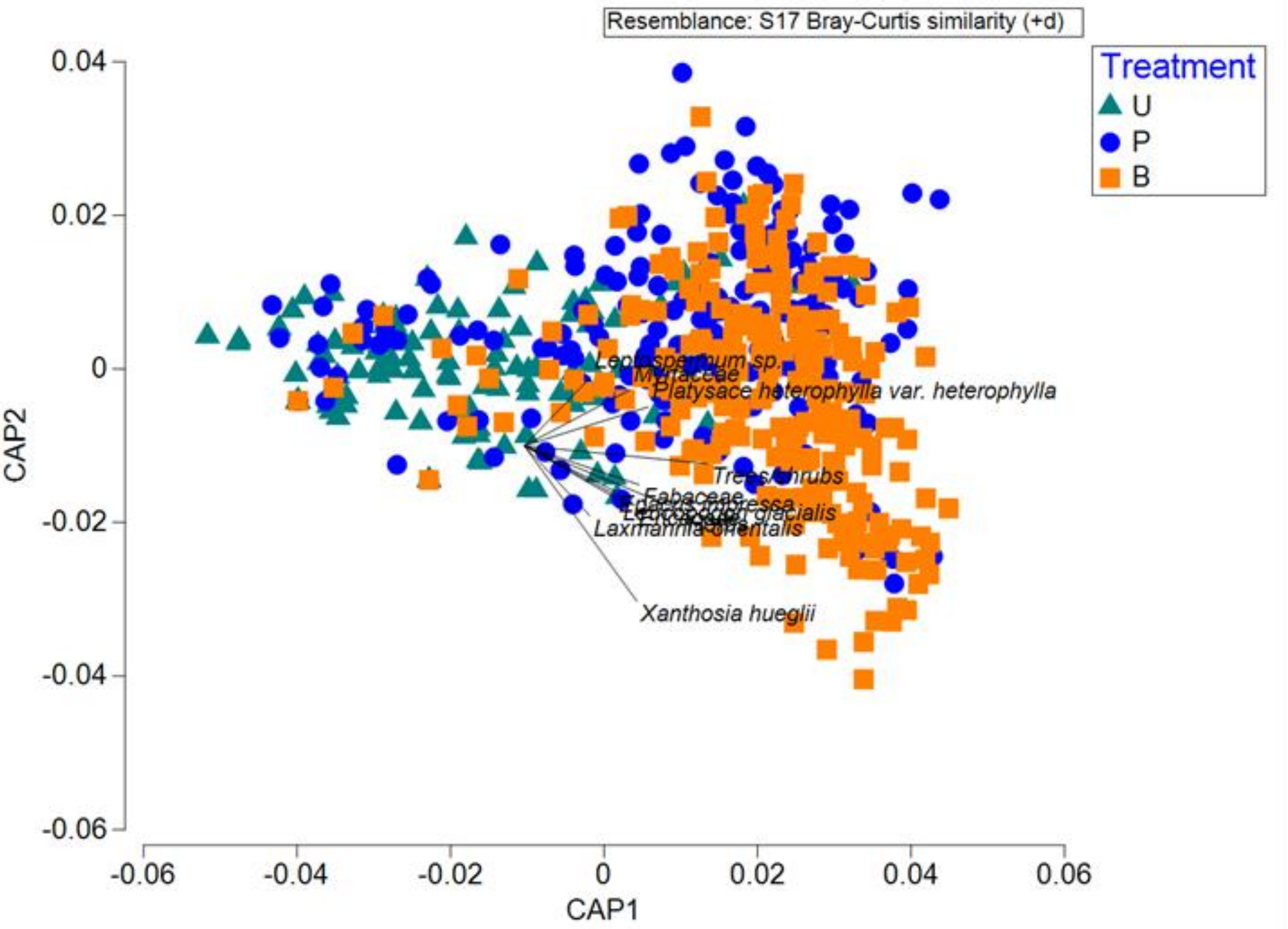
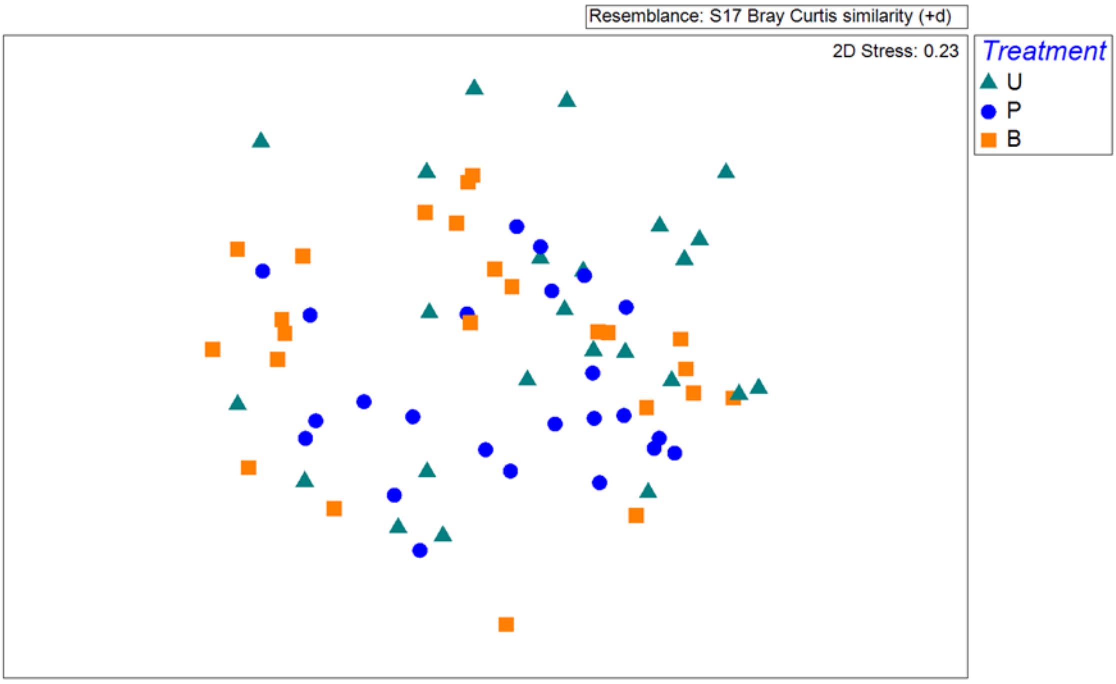


Figure 5: Canonical Analysis of Principle Components (CAP) of the effects burn treatments on seedling composition. Vectors where r≥0.3.

3.3 Effect of fire on mature species cover

I identified a difference in the cover of mature vegetation across treatments with the nMDS plot displaying similar clustering for burnt and patchy and high dispersion for unburnt (nMDS stress=0.23, Figure 6a). As the stress value was greater than 0.2, further cross-checking was required to confirm observations. The ANOSIM pairwise comparisons confirmed that there was a difference between unburnt and patchy (R=0.061, p=0.031), and there was a trend indicating the difference between unburnt and burnt (R=0.045, p=0.076) but no difference between patchy and burnt. SIMPER results between unburnt and patchy (average dissimilarity = 74.52) revealed that 13 species contributed to >50% of dissimilarity between the treatments. Of those species, there were seven shrubs and six grasses/sedges/rushes (Table A1). Alternatively, exploring the nMDS plot in relation to site indicated tight, distinct clustering for site compared to burn treatments (Figure 6b). ANOSIM results confirmed differences of species cover across sites (Global R=0.376, p=0.001), with pairwise comparisons confirming differences between all three sites.

a)



b)

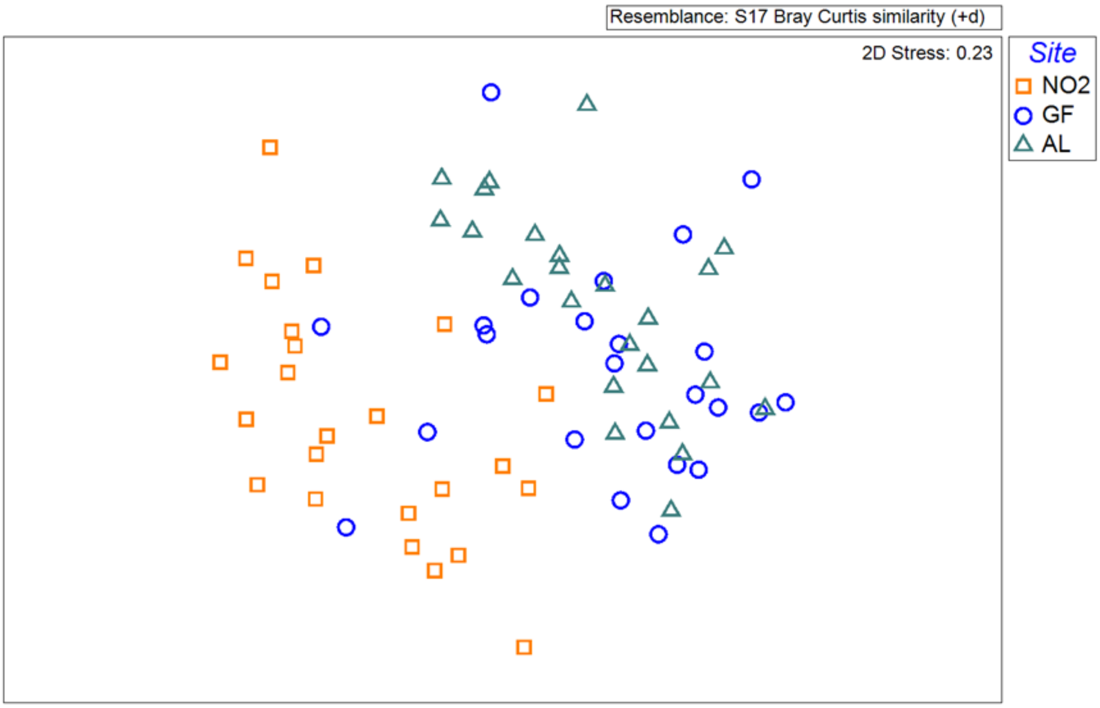


Figure 6: Non-metric multidimensional plot visualising differences in cover of mature vegetation of a) burn treatment and b) site. Treatments include unburnt (U), patchy (P) and burnt (B). Sites include No 2 Rd (NO2), Gum Flats Rd (GF) and Allardyce Trk (AL).

3.4 Effect of fire on seedling functional group richness

I found that the richness of obligate seeder seedlings in unburnt quadrats was lower than in burnt quadrats (Z=-7.516, df=2,715, p<0.001). Patchy quadrats trended towards lower obligate seeder richness than burnt quadrats (Z=-1.915, df=2,715, p=0.056) (Figure 7a). Richness of facultative seeding species was higher in burnt quadrats compared to unburnt (Z=7.248, df=2,715, p<0.001). I found no difference between burnt and patchy quadrats for facultative seeders (Figure 7b).

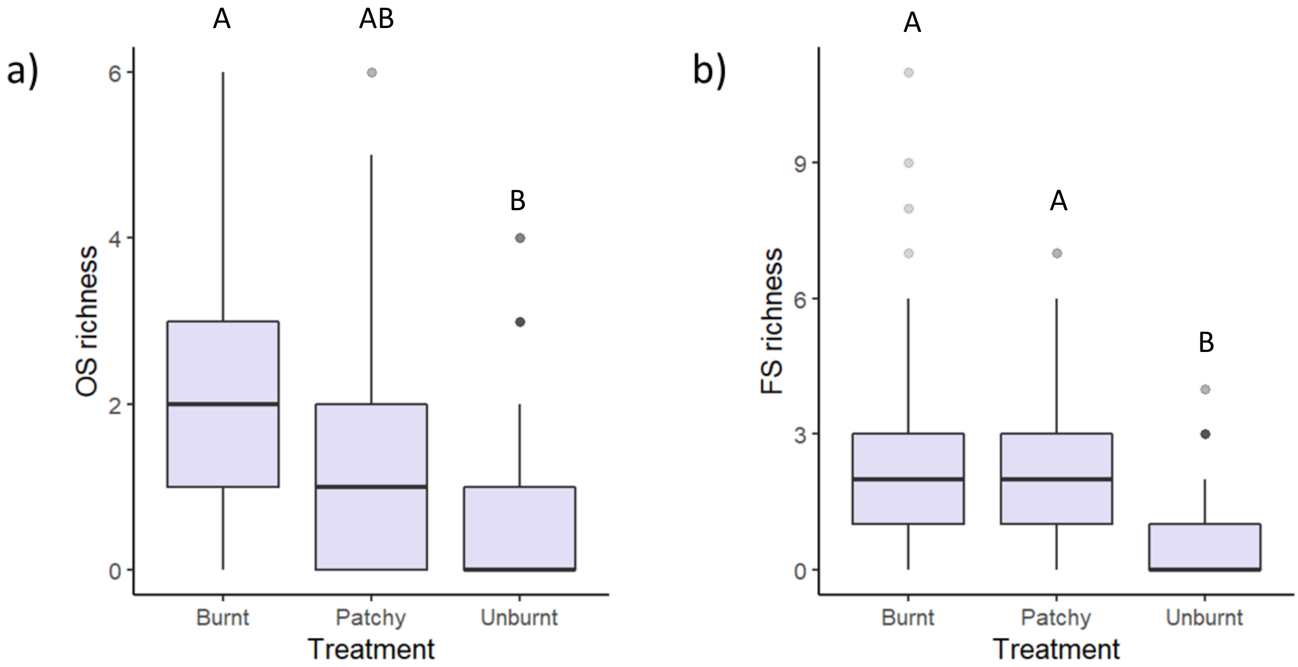


Figure 7: Seedling functional group richness across burn treatments for a) obligate seeder (OS) richness and b) facultative seeder (FS) richness. Different uppercase letters represent statistically significant differences (p<0.05). Shared letters denote no difference.

3.5 Comparison of seedling and mature vegetation composition

I identified a difference in composition between seedlings and mature vegetation with distinct clustering by age across all treatments (stress: unburnt=0.13; patchy=0.15; burnt=0.16) (Figure 8). ANOSIMs confirmed the differences between ages across all treatments (unburnt: Global R=0.447, p<0.001; patchy: Global R=0.474, p<0.001; burnt: Global R=0.399, p<0.001). There was 86.15% dissimilarity between seedlings and mature vegetation in unburnt, with 28 species contributing to 50% of that dissimilarity. 13 of these were shrub species, seven grasses/sedges/rushes species, six herbaceous species, one twiner and one fern species were present more often in quadrats in the mature vegetation (Table A2). There was 73% dissimilarity between seedlings and mature vegetation in patchy, with 33 species contributing to >50% of that dissimilarity. 19 of these are shrub species, however, six of these had similar abundance in seedling and mature, and two were more abundant as seedlings. 11 of these shrub species were more abundant as mature vegetation (Table A3). There was 73% dissimilarity between seedling and mature vegetation in burnt, with 33 species contributing to >50% of that dissimilarity. 15 of those species are shrubs, with 13 that were more abundant in the mature vegetation. Six of the species contributing to the dissimilarity between ages were grasses/sedges/rushes and eight of the species were herbaceous (Table A4).

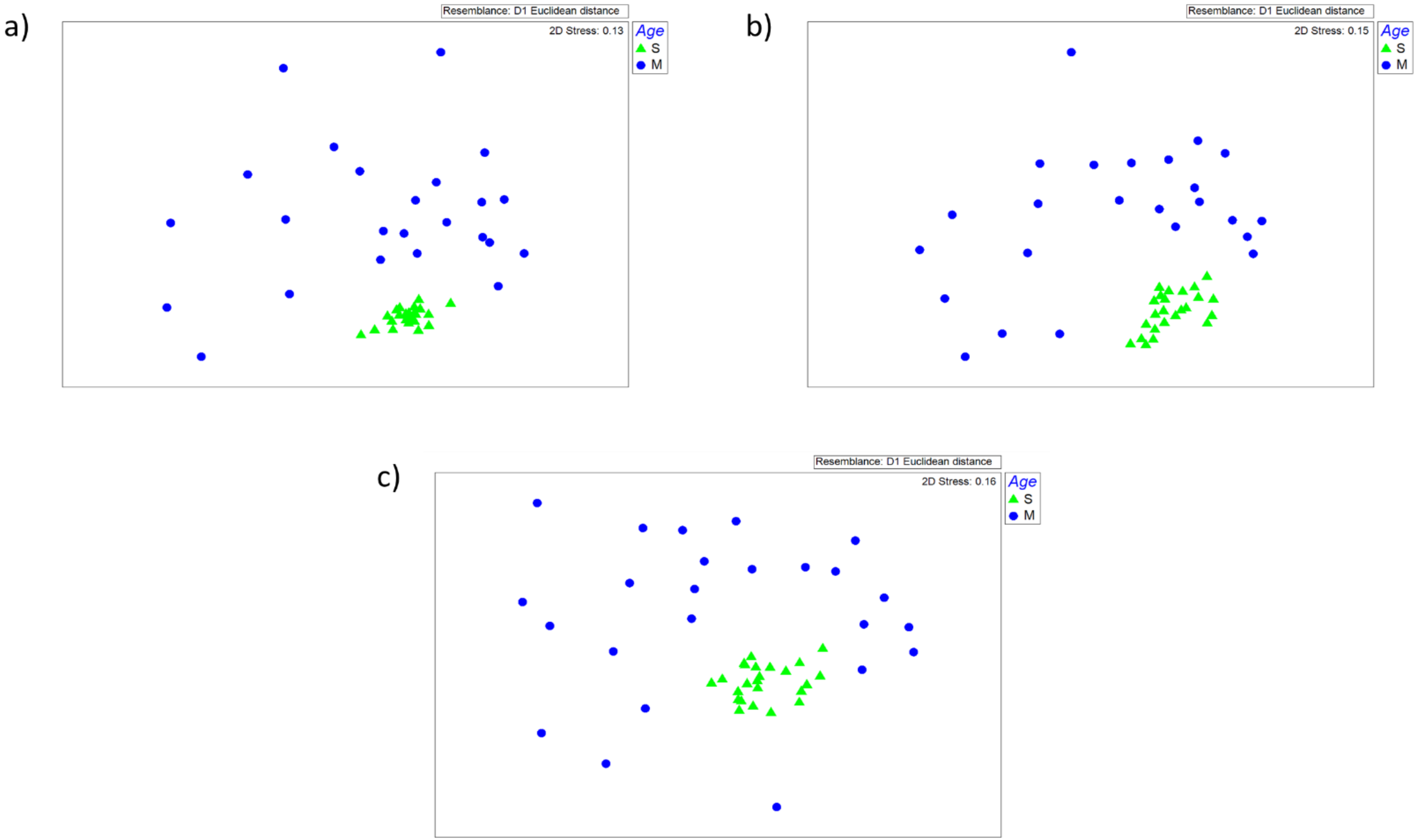


Figure 8: Non-metric multidimensional plot visualising differences in composition of seedling and mature vegetation across a) unburnt, b) patchy and c) burnt treatments.

3.6 Effect of fire on mature functional group richness and cover

I found no difference in the richness of functional groups of the mature vegetation across burn treatments (pseudo-F=1.8767, df=2,70, p=0.131). I confirmed there was no difference in dispersion across treatments (F=2.7077, df=2,70, p=0.082) and no effect of fire on the cover of obligate seeders and obligate resprouters across treatments (Figure 9). However, there was a difference in the cover of facultative seeders, with unburnt quadrats (Z=2.256, df=2,67, p=0.024) having higher FS cover than patchy and burnt quadrats (Figure 10).

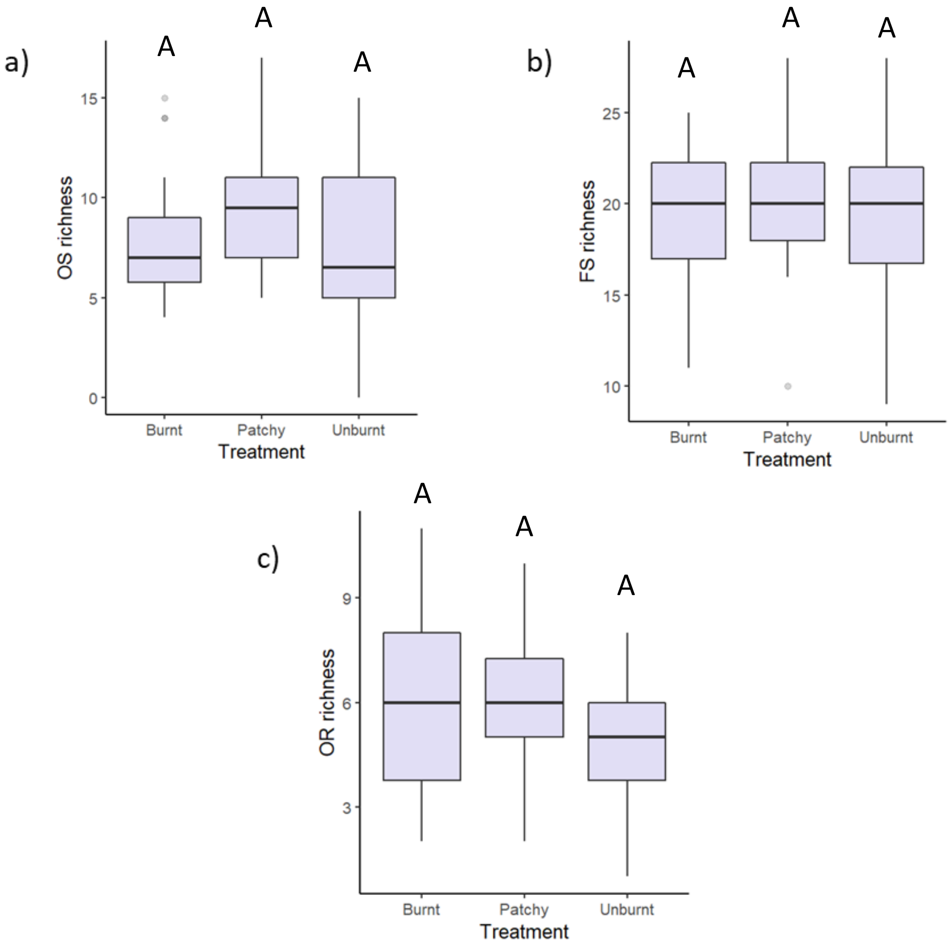


Figure 9: Mature vegetation functional group richness across burn treatments for a) obligate seeder (OS) richness, b) facultative seeder (FS) richness, and obligate resprouter (OR) richness. Different uppercase letters represent statistically significant differences (p<0.05). Shared letters denote no difference.

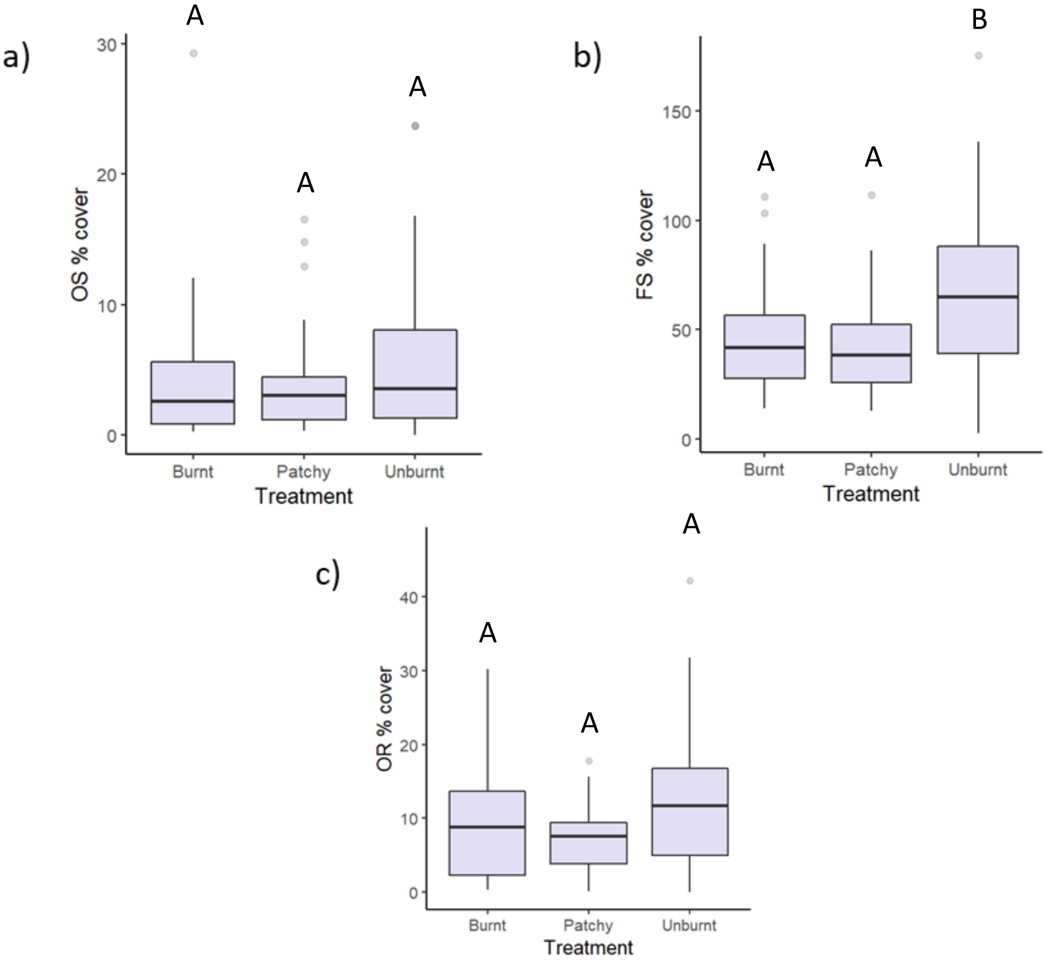


Figure 10: Mature vegetation functional group cover across burn treatments for a) obligate seeder (OS) cover, b) facultative seeder (FS) cover, and obligate resprouter (OR) cover. Different uppercase letters represent statistically significant differences (p<0.05). Shared letters denote no difference.

4. Discussion

4.1 Seedling germination

This study found that winter burns trigger germination within the Anglesea heathy woodlands, as there was a higher abundance of seedlings in the burnt and patchy treatments compared to unburnt. There was also a higher abundance of seedlings in burnt compared to patchy treatments. This was expected as the patchiness from a winter burn results in mature vegetation remaining, hence, leaving less space for seedling germination (Oliveira *et al.* 2015) It was predicted that the fires may not be intense enough to reach the required soil temperatures to trigger germination in patchy treatments. Auld and Bradstock (1996) found that soil temperatures after a winter burn in an open woodland with a shrubby understorey reached a maximum of 40°C, which was not hot enough to trigger germination for the species present in that landscape. However, our results indicate that the soil temperature was adequate. Heathlands dominated by a shrubby understorey burn at a high intensity due to the large volume of fine-fuel (Keith 2017). Although there was patchiness in the landscape, we observed scorch heights of up to 6m which indicates high intensity burns (Ooi *et al.* 2006b). Furthermore, *Leptospermum* sp. seedlings were observed to have germinated, which indicates the fire intensity reached the threshold required to crack open the woody capsules of these serotinous species. *Banksia marginata* seedlings were present in the patchy and burnt quadrats. *Banksia* spp. are known to require temperatures of 200°C-300°C to open the hard, woody cones and release the stored seed (Enright and Lamont 1989a), which further indicates the fires were of high intensity and therefore reaching temperatures capable of triggering recruitment for both canopy and soil-stored seed.

Burning outside of the historic fire season can disturb germination cues and cause a delay in germination of some species (Ooi *et al.* 2004). It was observed in our study that some seedlings emerged in spring 2022, indicating that the seeds delayed emergence for at least 12 months. If germination is delayed in the first winter, for example if the species has a form of physiological dormancy, then germination may not occur until the following autumn/winter when appropriate conditions are available (Enright and Lamont 1989b; Miller *et al.* 2021). Our seedling surveys were conducted 15 months after the burns to allow enough time to capture all species that were going to germinate, which means any seedlings that germinated in the following seasons were also recorded in the surveys. Delayed germination can increase seedling mortality rates, as germinants have to compete for space, light and nutrients with other vegetation that germinated or resprouted at least 12 months prior (Ooi 2010). Hence the timing of these winter burns may alter community composition.

Our study identified low abundance of seedlings for some species. For example, *Acrotriche serrulata* is an OS Ericaceous shrub that is commonly found in heathy woodlands (Department of Sustainability and Environment 2004). Across all three study sites, only nine seedlings were recorded for this species. However, the presence of mature individuals was noted in 31 of the total 72 quadrats surveyed. In contrast, the FS Myrtaceous shrub *Leptospermum continentale*, which possesses canopy-stored seed, had 1,018 seedlings across all study sites. This indicates that winter burns are favouring the germination of some species over others, which in the long-term, can lead to compositional shifts. Miller *et al.* (2021) found that seedling recruitment in Banksia woodlands in Perth, WA during the wet season (winter) was significantly lower than the abundance of seedlings during the historical fire season. It is not known how many seedlings are required to sustain a population in a heathy woodland and this study makes an important contribution by adding to the knowledge of recruitment rates after aseasonal burns.

While we found a high abundance of seedlings after this winter burn, there were compositional differences with respect to seedling functional groups among burnt treatments. Patchy treatments trended towards having lower obligate seeder seedling richness compared to burnt treatments. Although germination had been triggered in patchy treatments, not all obligate seeders germinated. Soil moisture levels influence the patchiness of a burn (Oliveira *et al.* 2015), with more moisture leading to higher patchiness. Le Fer and Parker (2005) conducted a study on the effects of soil moisture on germination of chaparral (shrubland) species. They found that the higher moisture levels of a spring burn can benefit germination of fire-stimulated seeds, as the moisture can help break the physical dormancy of hard-coated seeds (Le Fer and Parker 2005). The findings of our study contradict this. Potentially higher moisture levels where patchy burns occurred did not facilitate the germination for all obligate seeders. As patchiness is caused by higher soil and fuel moisture levels, burn intensity is decreased (Burrows *et al.* 2008), which decreases the soil temperature during a burn (Badía *et al.* 2017). This may explain why some obligate seeders did not have dormancy broken and a germination trigger.

While there is a large body of literature describing the impact of altered fire regimes on plant communities (Bradstock and Auld 1995; Ooi *et al.* 2006b; Enright *et al.* 2011), considerably less is known about species specific responses (Chick *et al.* 2019). Investigating the composition of seedlings at the species level, burnt quadrats were associated with more *Leucopogon glacialis,* an OS Ericaceous shrub that requires high temperatures to break seed dormancy and therefore recruits most successfully after high intensity fires (Enright *et al.*

1997). Patchy treatments were associated with more *Leptospermum* spp., a FS Myrtaceous shrub with canopy-stored seed. Low fire intensity is required to open the woody capsules of this genera (Clarke *et al.* 2010), which explains why seedlings were present in both burnt and patchy quadrats. However, higher intensity fires may incinerate the woody capsules preventing germination (Etchells *et al.* 2020) which may explain the difference in proportion of seedlings between these treatments. The difference in composition gives further evidence of the variability of intensity reached during a winter burn (Penman *et al.* 2007).

There was a difference in the composition between seedlings and mature vegetation across all treatments. The main aim of this project was to determine if winter burns are facilitating the necessary germination cues for the Anglesea heathy woodlands. If all species that were present in the mature vegetation also had a presence of seedlings, then this would indicate that winter burns are facilitating germination of the full suite of species. However, there were four obligate seeders that were predicted to have seedlings but were not present in any treatment (Table 1). Two of these species were shrubs in the Fabaceae family, and whilst both species had low presence in the landscape and require high intensity to break seed dormancy (Palmer *et al.* 2018), post-fire germination was expected as they are obligate seeders. As the germination of other Fabaceae shrubs was recorded, e.g. *Platylobium obtusangulum*, this study highlights the importance of studying species level post-fire responses to understand the effect of aseasonal fires and potential compositional shifts in the landscape.

There was no difference in the richness of facultative seeder seedlings between burnt and patchy treatments. Three facultative seeders did not have any seedlings present in any treatment. These were two shrubs and one grass. Facultative seeders are capable of resprouting after fire if the cues to trigger germination and environmental conditions prevent successful seedling recruitment (Lamont *et al.* 1999). This enables species to persist in the landscape. However, if burns occur at a higher frequency than the system is adapted to, facultative seeders may not be capable of replenishing the required nutrients for resprouting after the next fire, hence the population could be depleted (Enright *et al.* 2011). Therefore, if resprouting vigour is depleted under frequent burns and facultative seeders are not capable of germinating after winter burns, this could further change the composition of the landscape.

Table 1: List of species with X denoting seedling presence with low abundance seedling in that treatment. No X indicates no presence of seedlings of that species.

Species	**Lifeform**	**Functional group**	**Patchy**	**Burnt**
Allittia uliginosa	Herb	OS		X
Amperea xiphoclada	Shrub	FS	X	
Bossiaea prostrata	Shrub	OS		
Daviesia brevifolia	Shrub	OS		
Dillwynia sericea	Shrub	FS		
Hakea ulicina	Shrub	OS		X
Hibbertia riparia	Shrub	FS		X
Hibbertia sericea	Shrub	FS		
Lepidosperma filiforme	Grass/sedge/rush	FS		
Leucopogon virgatus	Shrub	FS	X	
Lobelia gibbosa	Herb	OS		
Lomandra micrantha	Grass/sedge/rush	FS	X	
Poranthera microphylla	Herb	OS		

Across all treatments, one *Hakea ulicina* seedling germinated. However, many burnt mature individuals of this species with open capsules were noted throughout the study sites. Lee (1984) found that after a fire in autumn 1980 in the Anglesea region, a high abundance of *H. ulicina* seedlings were observed to have germinated in winter. This may indicate the importance of season of fire as a germination cue for *H. ulicina*. Burning in winter may not enable sufficient time for capsules to open and release seed and germinate within the winter season. Hence winter burns may not favour the persistence of this species.

There was a difference in composition between seedlings and mature vegetation across all treatments, being least similar in unburnt quadrats. The dissimilarity between seedling and mature vegetation composition for both burnt and patchy treatments was 73%, with 33 species causing >50% of the dissimilarity, however it was a different suite of species in each treatment. In patchy treatments, there were seven obligate seeders present more frequently in mature vegetation compared to their presence as seedlings. These species included three of the species noted in the unburnt quadrats, as well as one herb, *Opercularia varia,* and three shrubs, *Leucopogon glacialis, Acrotriche serulata,* and *Pultenaea humilis*. Five obligate seeders were present more often in the mature vegetation in burnt quadrats. The species include two shrubs, *Pultenaea humilis,* and *Hibbertia fasiculata,* two herbs, *Drosera macrantha,* and *Opercularia varia*, and one twiner, *Cassytha glabella.* The higher presence of the shrubs *Pultenaea humilis* and *Hibbertia fasiculata* may be due to these species potentially having faster growth rates due to less resource allocation to their comparatively softer leaves than the tough, sclerophyllous leaves (Read and Sanson 2003) of many other heathy shrubs present in this landscape. The herb species that are more present in the mature vegetation are likely 2021 germinants that had reached maturity in the 12 months since the winter burns.

4.2 Persistence of mature species

One aim of planned burning is to create heterogeneity in the landscape by burning different areas at different times. This large-scale mosaic allows for stands of multiple ages and stages of sexual maturity to exist at the same time (Duncan *et al.* 2015). However, the patchiness from a winter burn can create a fine-scale mosaic within a burn unit. This patchiness can allow for the persistence of mature individuals, specifically obligate seeders. This was observed in this study, as the richness of obligate seeders did not change between burnt, patchy and unburnt treatments. Therefore, diversity did not decrease from these winter burns, showing that individuals are persisting in the landscape. Another way to assess the impact of winter burns on obligate seeders persistence is via the cover of mature individuals surviving the fire. There was no difference for obligate seeders cover between all treatments. This was not expected, as burnt quadrats were initially selected on the basis that all mature individuals were killed, and at the time of selection this was the case. Our vegetation surveys were conducted 15 months after the initial winter burn, which is enough time for herbaceous species to reach maturity (Guo 2001). This could explain why the cover of obligate seeders was not different between the treatments, as the burnt quadrats contained a higher cover of herbaceous species compared to patchy and unburnt, whilst also possessing similar herb richness between burnt and patchy. This may be representing an early successional stage, and in following years the composition of vegetation will shift to be more shrub dominated (Posamentier *et al.* 1981).

4.3 Management recommendations

This study has demonstrated that prescribed burns in winter have the capacity to facilitate germination for obligate seeders. Not every species germinated, and some were in low abundance hence may not be enough to sustain a population. Consequently, this could lead to compositional shifts over time and land managers may need to monitor specific species at risk of disappearing from the landscape. For example, *Hakea ulicina* has already been identified as a species of concern and may need a species management plan to conserve this shrub in the Anglesea Heath. The fine-scale mosaic within our burn units demonstrates the variability of fire intensity from a winter burn which can be utilised to facilitate the persistence of obligate seeders, to ensure that there are individuals in the landscape with seed present in the event of future bushfires or prescribed burns. Particularly if prescribed burns are applied at higher frequencies to manage fuel loads and risk of bushfires. This study will contribute to the fire management strategies utilised by the land managers of the Anglesea Heathlands. As recommended by Chick *et al.* (2019), ongoing monitoring of species level responses to these altered fire regimes and winter burns is essential.

4.4 Future research

The aim of this research was to explore the impact of winter burns on germination, but we were limited to using only three sites in the Anglesea heathy woodlands that had winter prescribed burns. Furthermore, each site had topographic and fire history differences that may contribute to compositional differences in the vegetation. Whilst these differences were considered when building our models, we interpreted our results with caution. The germination responses recorded in this study will contribute to the Vital Attributes Database of post-fire vegetation responses (Arthur Rylah Institute 2015). However, there are gaps in this database and further research is required into species level responses to fire. The surveys conducted in this study only show a snapshot of the vegetation response to the first winter burns in the Anglesea heathy woodlands. Further research could explore the long-term effects of winter burns with longitudinal studies or conduct comparative studies of the abundance of seedlings germinated after different seasons within the same region. This data would also build on our understanding of the levels of recruitment required for populations to persist in a landscape. No heat cues reached the seedbank in the unburnt treatment yet there was some germination response. Likely it is due to smoke from the adjacent burnt areas reaching the unburnt quadrats, but to date this has not been documented and requires further investigation to quantify the extent to which this may promote recruitment in nearby unburnt areas.

5. Conclusion

This study found that winter burns can facilitate the germination of obligate seeding species in the Anglesea heathy woodlands. There was a higher abundance of seedlings in burnt and patchy compared to unburnt treatments. However, caution must be taken with this conclusion as the abundances observed here may not be high enough to sustain populations and we have no comparative data of seedling abundance after bushfires in these heathlands. The fine-scale mosaic created from winter burns facilitated the persistence of mature obligate seeders in the landscape which may assist with the long-term survival of these species. As it is likely that land managers will continue to conduct prescribed burns in winter in response to climate change, not just in heathland systems, it is imperative to continue surveying the impacts of winter burns and monitoring the response of vegetation communities.

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Appendices

Table A1: Results from the mature vegetation species cover SIMPER between unburnt and patchy treatments. Cells highlighted green indicates the species that had higher average cover in that treatment. Functional groups include facultative seeders (FS), obligate resprouters (OR) and unknown response (U).

Species	Lifeform	Functional group	Av.Abund Unburnt	Av.Abund Patchy	Av.Diss	Diss/SD	Contrib%	Cum.%
Leptospermum myrsinoides	Shrub	FS	15.32	9.3	9.08	1.05	12.18	12.18
Leptospermum continentale	Shrub	FS	13.44	3.63	7.53	0.85	10.1	22.28
Xanthorrhoea australis	Grass/sedge/rush	U	6.13	6.84	5.12	0.99	6.87	29.15
Hypolaena fastigiata	Grass/sedge/rush	FS	7.41	3.68	4.36	0.79	5.86	35.01
Eucalyptus willisii	Shrub	U	4.49	4.78	4.14	1.01	5.55	40.56
Eucalyptus obliqua	Shrub	FS	2.71	3.85	3.39	0.73	4.55	45.11
Gahnia radula	Grass/sedge/rush	OR	5.12	2.7	3.15	0.67	4.23	49.34
Lepidosperma filiforme	Grass/sedge/rush	FS	4.13	1.5	2.97	0.88	3.98	53.32
Schoenus lepidosperma	Grass/sedge/rush	FS	3.88	1.14	2.35	0.65	3.15	56.47
Allocasuarina misera	Shrub	FS	3.55	1.9	2.24	1.08	3.01	59.48
Lepidosperma semiteres	Grass/sedge/rush	FS	3.25	1.4	2.21	0.61	2.96	62.44
Platylobium obtusangulum	Shrub	FS	3.14	1.41	2.21	0.7	2.96	65.4
Banksia marginata	Shrub	FS	2.67	2.74	1.8	1.02	2.42	67.82

Table A2: Results from the unburnt treatment seedling and mature vegetation composition SIMPER. Cells highlighted green indicates the species that had higher average cover in that treatment. Functional groups include facultative seeders (FS), obligate seeders (OS), obligate resprouters (OR) and unknown response (U).

Species	**Family**	**Lifeform**	**Functional group**	**Av.Abund Seedling**	**Av.Abund Mature**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Banksia marginata	Proteaceae	shrub	FS	0	1	2.46	3.9	2.86	2.86
Burchardia umbellata	Colchicaceae	herb	OR	0	0.88	2.19	2.13	2.55	5.41
Xanthorrhoea australis	Asphodelaceae	grass/sedge/rush	FS	0	0.79	1.9	1.7	2.2	7.61
Persoonia juniperina	Proteaceae	shrub	FS	0	0.79	1.88	1.72	2.18	9.79
Gahnia radula	Cyperaceae	grass/sedge/rush	OR	0	0.75	1.85	1.53	2.14	11.93
Hypolaena fastigiata	Restionaceae	grass/sedge/rush	FS	0	0.71	1.79	1.41	2.08	14.01
Schoenus lepidosperma	Cyperaceae	grass/sedge/rush	U	0.04	0.71	1.78	1.37	2.07	16.08
Drosera auriculata	Droseraceae	herb	FS	0	0.71	1.72	1.4	2	18.08
Gonocarpus tetragynus	Haloragaceae	herb	FS	0.17	0.79	1.69	1.35	1.96	20.04
Lomandra filiformis	Asparagaceae	grass/sedge/rush	FS	0	0.71	1.67	1.39	1.94	21.98
Leptospermum continentale	Myrtaceae	shrub	FS	0.21	0.75	1.67	1.24	1.93	23.92
Allocasuarina misera	Casuarinaceae	shrub	FS	0	0.67	1.59	1.32	1.84	25.76
Platylobium obtusangulum	Fabaceae	shrub	FS	0.17	0.75	1.58	1.29	1.83	27.6
Leptospermum myrsinoides	Myrtaceae	shrub	FS	0.33	0.88	1.55	1.19	1.8	29.4
Dillwynia cinerascens s.l.	Fabaceae	shrub	OS	0.33	0.83	1.54	1.16	1.78	31.18
Cassytha glabella	Lauraceae	twiner	OS	0.04	0.63	1.5	1.19	1.74	32.92
Drosera macrantha subsp. Planchonii	Droseraceae	herb	OS	0	0.58	1.47	1.11	1.71	34.63
Acacia suaveolens	Fabaceae	shrub	FS	0.17	0.63	1.41	1.1	1.63	36.26
Lindsaea linearis	Lindsaeaceae	fern	FS	0	0.54	1.41	1.02	1.63	37.9
Epacris impressa	Ericaceae	shrub	FS	0.29	0.67	1.36	1.07	1.57	39.47
Xanthorrhoea minor subsp. lutea	Asphodelaceae	grass/sedge/rush	FS	0	0.58	1.35	1.11	1.57	41.04
Eucalyptus willisii	Myrtaceae	shrub	U	0.04	0.5	1.33	0.93	1.54	42.59
Lepidosperma filiforme (1mm)	Cyperaceae	grass/sedge/rush	FS	0	0.58	1.32	1.13	1.54	44.12
Dillwynia glaberrima	Fabaceae	shrub	FS	0.17	0.5	1.32	0.95	1.53	45.65
Monotoca scoparia	Ericaceae	shrub	FS	0.04	0.5	1.24	0.93	1.44	47.09
Xanthosia huegelii	Apiaceae	herb	FS	0.5	0.63	1.24	0.94	1.43	48.53
Platysace heterophylla var. heterophylla	Apiaceae	herb	U	0.5	0.46	1.23	0.94	1.43	49.95
Hibbertia fasciculata var. prostrata	Dilleniaceae	shrub	OS	0.29	0.5	1.21	0.95	1.4	51.35

Table A3: Results from the patchy treatment seedling and mature vegetation composition SIMPER. Cells highlighted green indicates the species that had higher average cover in that treatment. Functional groups include facultative seeders (FS), obligate seeders (OS), obligate resprouters (OR) and unknown response (U).

Species	**Family**	**Lifeform**	**Functional group**	**Av.Abund Seedling**	**Av.Abund Mature**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Banksia marginata	Proteaceae	shrub	FS	0.08	0.96	1.64	2.46	2.25	2.25
Lomandra filiformis	Asparagaceae	grass/sedge/rush	FS	0.04	0.88	1.54	2.14	2.12	4.37
Burchardia umbellata	Colchicaceae	herb	OR	0	0.79	1.49	1.84	2.04	6.4
Xanthorrhoea australis	Asphodelaceae	grass/sedge/rush	FS	0	0.79	1.48	1.83	2.03	8.43
Drosera auriculata	Droseraceae	herb	FS	0.04	0.79	1.42	1.72	1.95	10.38
Gahnia radula	Cyperaceae	grass/sedge/rush	OR	0	0.75	1.36	1.67	1.87	12.25
Cassytha glabella	Lauraceae	twiner	OS	0.13	0.75	1.27	1.42	1.75	14
Allocasuarina misera	Casuarinaceae	shrub	FS	0.17	0.75	1.24	1.36	1.7	15.7
Eucalyptus willisii	Myrtaceae	shrub	U	0.13	0.71	1.2	1.34	1.65	17.35
Xanthorrhoea minor subsp. lutea	Asphodelaceae	grass/sedge/rush	FS	0	0.63	1.19	1.24	1.63	18.98
Gonocarpus tetragynus	Haloragaceae	herb	FS	0.29	0.83	1.18	1.29	1.62	20.6
Schoenus lepidosperma	Cyperaceae	grass/sedge/rush	U	0.25	0.71	1.14	1.2	1.56	22.16
Lomandra micrantha s.l.	Asparagaceae	grass/sedge/rush	FS	0.04	0.63	1.1	1.23	1.51	23.67
Lepidosperma filiforme	Cyperaceae	grass/sedge/rush	FS	0	0.63	1.1	1.25	1.51	25.18
Hypolaena fastigiata	Restionaceae	grass/sedge/rush	FS	0.08	0.58	1.08	1.11	1.49	26.67
Pimelea humilis	Thymelaeaceae	shrub	FS	0.38	0.79	1.08	1.12	1.49	28.15
Tetratheca ciliata	Elaeocarpaceae	shrub	FS	0.29	0.67	1.07	1.11	1.47	29.62
Monotoca scoparia	Ericaceae	shrub	FS	0.13	0.58	1.06	1.1	1.45	31.08
Dillwynia cinerascens s.l.	Fabaceae	shrub	OS	0.42	0.83	1.04	1.09	1.43	32.5
Lepidosperma semiteres	Cyperaceae	grass/sedge/rush	FS	0.04	0.58	1.03	1.13	1.42	33.92
Platylobium obtusangulum	Fabaceae	shrub	FS	0.42	0.79	1.02	1.08	1.4	35.32
Eucalyptus sp.	Myrtaceae	shrub	U	0.54	0.08	1.01	1.04	1.38	36.7
Persoonia juniperina	Proteaceae	shrub	FS	0.04	0.54	1	1.05	1.37	38.07
Hibbertia fasciculata var. prostrata	Dilleniaceae	shrub	OS	0.42	0.58	0.97	1	1.33	39.4
Dillwynia glaberrima	Fabaceae	shrub	FS	0.46	0.58	0.95	0.99	1.3	40.7
Acacia suaveolens	Fabaceae	shrub	FS	0.5	0.75	0.94	0.98	1.29	41.98
Leptospermum continentale	Myrtaceae	shrub	FS	0.5	0.71	0.94	0.97	1.29	43.27
Opercularia varia	Rubiaceae	herb	OS	0.5	0.88	0.94	0.98	1.29	44.56
Leucopogon glacialis	Ericaceae	shrub	OS	0.46	0.5	0.92	0.97	1.27	45.83
Acrotriche serrulata	Ericaceae	shrub	OS	0.08	0.5	0.92	0.98	1.26	47.09
Pultenaea humilis	Fabaceae	shrub	OS	0.04	0.5	0.9	0.98	1.24	48.33
Rhytidosporum procumbens	Pittosporaceae	shrub	OS	0.46	0.33	0.9	0.95	1.24	49.57
Leptospermum myrsinoides	Myrtaceae	shrub	FS	0.54	0.75	0.89	0.93	1.23	50.8

Table A4: Results from the burnt treatment seedling and mature vegetation composition SIMPER. Cells highlighted green indicates the species that had higher average cover in that treatment. Functional groups include facultative seeders (FS), obligate seeders (OS), obligate resprouters (OR) and unknown response (U).

Species	Family	Lifeform	Functional group	Av.Abund Seedling	Av.Abund Mature	Av.Diss	Diss/SD	Contrib%	Cum.%
Drosera auriculata	Droseraceae	herb	FS	0	0.96	1.81	3.79	2.5	2.5
Burchardia umbellata	Colchicaceae	herb	OR	0	0.88	1.65	2.4	2.27	4.78
Lomandra filiformis	Asparagaceae	grass/sedge/rush	FS	0.04	0.88	1.6	2.15	2.22	7
Banksia marginata	Proteaceae	shrub	FS	0.13	0.92	1.54	1.96	2.12	9.12
Gahnia radula	Cyperaceae	grass/sedge/rush	OR	0	0.79	1.47	1.84	2.03	11.15
Allocasuarina misera	Casuarinaceae	shrub	FS	0.04	0.75	1.4	1.57	1.93	13.08
Xanthorrhoea australis	Asphodelaceae	grass/sedge/rush	FS	0	0.67	1.26	1.36	1.74	14.82
Persoonia juniperina	Proteaceae	shrub	FS	0.08	0.67	1.2	1.28	1.66	16.48
Gonocarpus tetragynus	Haloragaceae	herb	FS	0.25	0.75	1.16	1.26	1.61	18.08
Pimelea humilis	Thymelaeaceae	shrub	FS	0.08	0.63	1.13	1.2	1.56	19.64
Pultenaea humilis	Fabaceae	shrub	OS	0.17	0.63	1.11	1.14	1.54	21.17
Lomandra micrantha s.l.	Asparagaceae	grass/sedge/rush	FS	0	0.58	1.08	1.16	1.5	22.67
Goodenia lanata	Goodeniaceae	herb	U	0	0.58	1.08	1.14	1.49	24.16
Schoenus lepidosperma	Cyperaceae	grass/sedge/rush	U	0.25	0.58	1.06	1.06	1.46	25.62
Platylobium obtusangulum	Fabaceae	shrub	FS	0.38	0.75	1.05	1.1	1.45	27.08
Monotoca scoparia	Ericaceae	shrub	FS	0.04	0.54	1.05	1.06	1.45	28.52
Laxmannia orientalis	Asparagaceae	herb	FS	0.25	0.63	1.04	1.1	1.44	29.96
Cassytha glabella	Lauraceae	twiner	OS	0.25	0.58	1.03	1.06	1.42	31.38
Lepidosperma semiteres	Cyperaceae	grass/sedge/rush	FS	0.21	0.58	1.02	1.07	1.41	32.79
Xanthorrhoea minor subsp. lutea	Asphodelaceae	grass/sedge/rush	FS	0	0.5	0.98	0.98	1.36	34.14
Tetratheca ciliata	Elaeocarpaceae	shrub	FS	0.33	0.54	0.98	1	1.36	35.5
Hypolaena fastigiata	Restionaceae	grass/sedge/rush	FS	0.13	0.5	0.98	0.97	1.35	36.85
Drosera macrantha subsp. Planchonii	Droseraceae	herb	OS	0	0.5	0.97	0.98	1.34	38.19
Hibbertia fasciculata var. prostrata	Dilleniaceae	shrub	OS	0.42	0.54	0.97	0.99	1.34	39.53
Eucalyptus willisii	Myrtaceae	shrub	U	0.13	0.5	0.96	0.98	1.33	40.85
Rhytidosporum procumbens	Pittosporaceae	shrub	OS	0.5	0.5	0.96	0.97	1.32	42.18
Epacris impressa	Ericaceae	shrub	FS	0.54	0.63	0.94	0.95	1.3	43.48
Leucopogon glacialis	Ericaceae	shrub	OS	0.58	0.58	0.94	0.95	1.3	44.78
Acacia suaveolens	Fabaceae	shrub	FS	0.33	0.5	0.93	0.98	1.29	46.07
Opercularia varia	Rubiaceae	herb	OS	0.54	0.67	0.93	0.95	1.29	47.35
Viola cleistogamoides	Violaceae	herb	OR	0.08	0.5	0.92	0.97	1.27	48.62
Hibbertia riparia	Dilleniaceae	shrub	FS	0.21	0.46	0.89	0.92	1.23	49.86
Conospermum mitchellii	Proteaceae	shrub	FS	0.21	0.42	0.88	0.89	1.21	51.07