

A pilot study into ecological burning in forests as part of a species conservation plan

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Abstract. Pearson MW. 2021. A pilot study into ecological burning in forests as part of a species conservation plan. *Biodiversitas* 22: 1296-1303. Fire management and the process of managing communities has become an increasingly topical subject due to recent events. The role of fire for fuel reduction with areas set aside for conservation may not be compatible as a seed recruitment tool for *Allocasuarina robusta*. Presently, fire as a recruitment tool on *A. robusta* is not well understood. The pilot study aims to examine the latent seedbank ability to contribute to the conservation of *A. robusta* when ecological burning is part of a fire management plan. The investigation examined the soil seed bank beneath *A. robusta* before and after an ecological burn as a greenhouse experiment. The experiment results demonstrated that a diverse range of species responds to a fire that may out-compete the seed recruitment from *A. robusta*. The results indicate that *A. robusta* may not be recruiting through seed. Competition appears to be a factor that may limit the ability of *A. robusta* to recruit from seed.

Keywords: Germination, restoration, seed bank, fire

INTRODUCTION

Anthropogenic land-use changes have altered vegetation communities directly or indirectly, resulting in changes to natural regimes, i.e. flooding or fire (Woolfrey and Ladd 2001; Bradford et al. 2008). Intensive agriculture in open *Eucalypt* woodlands and low-lying heath has reduced the extent and abundance of diversity in the South Australian Mount Lofty Ranges with 236 plant species listed as threatened or rare (Armstrong et al. 2003; Quarmby 2016). Changes to hydrological regimes and seasonal fire cycles facilitate the establishment of invasive species, which further alter hydrology and increase the effects of salinization. Since European settlement, 25% of swamps have disappeared, 49% represent degraded swamps, and 26% are relatively intact (Department for Environment and Heritage 2007). Some hydrophyte/geophyte species depend on specific hydrological or fire regimes, and as a consequence, when these environmental processes change, they become a threatened species (Bickford et al. 2008).

Since European settlement, the South Australian landscape has changed dramatically (Beinke et al. 2011; Morgan et al. 2020). *A. robusta* is a threatened species now restricted in distribution to 172km² in the Mount Lofty Ranges, in the south-eastern region of South Australia (Quarmby 2016). Most *A. robusta* populations reside in small roadside reserves, which are subject to ongoing disturbance (Quarmby 2016). Presently, environmental rehabilitation is occurring to restore hydrological regimes in Myponga Creek catchment, within the range of *A. robusta* (Bickford et al. 2008; Bradford et al. 2008; Bachmann and Farrington 2016). The works aim to restore

natural water regimes and restrict water movement to enable the water to meander across the landscape by creating localized flood-out areas to improve biodiversity and restore a more natural hydrological regime (Beinke et al. 2011).

Allocasuarina robusta, like other *Allocasuarina*, is considered serotinous species with seed released following a fire (Abbott 1984). However, fire-related germination can be variable and may reduce if a fire is too intense, and the fruit incurs heat shock (Ma et al. 2017). Mature *Allocasuarina* can reshoot from lignotubers after the mainstem's death (Ooi et al. 2007). However, the ability to regenerate from lignotubers requires augmentation with seeds to ensure long-term population viability (Wellington and Noble 1985; Ooi et al. 2007). Recovery for *A. robusta* may be achieved through ecological burning to initiate dormant seed release from fruit along the branches (Gtinster 1994; Ooi et al. 2007). However, we still do not understand if a fire is a useful management tool to aid the recovery process. Fire is one of the main drivers for population recruitment, as is the case for many other *Allocasuarina* species.

The presence of fire is an environmental variable that can select species based on their tolerance towards a fire (Ma et al. 2017; Sagra et al. 2019; Alahakoon et al. 2020; Tangney et al. 2020). Current natural resource management practice use of fire does not reflect past fire events (Sagra et al. 2019). Sagra et al. (2019) describes current management practices/policies, lead to increased fire intensities and fuel loads, promoting more severe fire events. The regeneration of vegetation selected for fire tolerance will appear as basal or lignotubers or serotinous seeders (Ooi et al. 2007; Lamont and Bellingham 2020).

How fire affects, the breeding system of a species would simulate or initiate regenerations from seed or through tubers (Alahakoon et al. 2020). Changes to the fire regimes described by Sagra et al. (2019) can lead to changes in the ecosystem process. Alahakoon et al. (2020) and Sagra et al. (2019) identify how fire applied for landscape management purposes can further exacerbate species selection from a fire as alluded to by Ma et al. (2017). The role of an ecological burn and the impact which the fire would have on a species is not well understood (Le Breton et al. 2019). An ecological burn aims to optimize natural regeneration by understanding population dynamics (Le Breton et al. 2019). The same can equally apply to understanding the parental role of serotinous species for seed recruitment (Lamont et al. 2020). When seed released or dormancy broken from a fire, the recruitment process requires an environment with greater resource availability and reduced resource competition (Lamont and Bellingham 2020; Tangney et al. 2020).

Lamont and Bellingham (2020) review discusses the role of recruitment from serotinous seeders and the indices to measure serotiny. However, fire tolerance and recovery identified as two different entities by Chick et al. (2018) as the measuring of fire intensity is through several parameters with the temperature being one parameter. Understanding the interrelationship with temperature can be vital; it will directly impact the species survival (Cochrane 2020). The investigation aims to test the effect of an ecological burn on *A. robusta* by determining if the latent soil seed bank supports seed recruitment of *A. robusta*.

MATERIALS AND METHODS

Study species

The climatic conditions *A. robusta* favor are the Fleurieu Peninsula's wettest parts (Department for Environment and Heritage 2007). The Fleurieu Peninsula has a temperate climate with moderately wet winters and hot, dry summers (Armstrong et al. 2003). Rainfall in the Fleurieu Peninsula can range from 400 to 1000 mm depending on altitude and aspect (Armstrong et al. 2003). *A. robusta* grows on soils described by the Department for Environment and Heritage (2007) as infertile acidic soils associated with peat bog. The soil types range from mottled yellow ironstone soils, gravelly duplex soils and sandy glacial outwash soils (Department for Environment and Heritage 2007). *A. robusta* occurs on sandy glacial outwash soils at Hindmarsh Tiers (Bickford et al. 2008).

Allocasuarina robusta occurs in the Kanmantoo bioregion, which includes the southern Mount Lofty Ranges, Fleurieu Peninsula and Kangaroo Island (Department for Environment and Heritage 2007). The Fleurieu Peninsula contains Eucalyptus open forests and woodlands. The habitat description for *A. robusta* is the peripheries of wetlands where the mesophytes and hydrophytes meet. The critically endangered Fleurieu Peninsula wetlands communities have legislative protection from the Commonwealth and South Australian state

government (Department for Environment and Heritage 2007).

Allocasuarina robusta a threatened species of the Mount Lofty Ranges described as a monoecious shrub with smooth bark (Jessop and Toelken 1986, Wilson and Johnson 1989). The branchlets and scales leaves of *A. robusta* are glabrous with the immature scale leaf appearing to overlap (Wilson and Johnson 1989). The female inflorescences produce aggregate fruit form a 3mm long peduncle; these may be sparsely pubescent or sessile on the peduncle (Jessop and Toelken 1986). The seed of *A. robusta* described as a samara with seed ranging in size from 5.5 – 6.0 mm (Wilson and Johnson 1989). *A. robusta* stores the seed above ground and then releases seed through an environmental trigger (Jessop and Toelken 1986, Quarmby 2016). Quarmby (2016) recommended an ecological burn for releasing the above-ground stored seed, to facilitate seed recruitment.

Ecological burns occurred in October 2017 and March 2018 at Stipiturus Conservation Park in the Southern Mount Lofty Ranges in South Australia, 11 km west of Mount Compass. Stipiturus Conservation Park is one of the largest conserved populations of *A. robusta* (Quarmby 2016). The park's proclamation was to conserve a regenerating swamp and protect threatened species previously; the park was once an agricultural enterprise (Bachmann and Farrington 2016).

Study design

Soil sampling occurred on 21st October 2017. Four soil samples (diameter 75 mm, depth 100 mm) were taken at 500 mm apart from each of the 18 *A. robusta*'s base. These samples included surface litter that may have retained *A. robusta* seed.

The four soil samples collected underneath each tree was batched into one larger single sample and then mixed and sieved to remove any material more significant than 10 mm by 10 mm (i.e., gravel or sticks). The soil was then placed in 400 ml plastic punnets and assigned to a treatment. Each treatment was replicated five times and randomly distributed in a four-block experiment design. The base of a punnet was covered to a depth of 15 mm using a-sub-sample of soil. Each batched soil sample was assigned a code related to the tree of origin. Punnets were assigned either as controls (126 punnets used) or as one of two manipulative treatment punnets (smoke water [63 punnets used] or direct fire [63 punnets used]), a total of 252 punnets formed the experimental design.

Smoke water was purchased as a commercial product from Sure Gro and applied at the rate of 1-part smoke water to 10 parts water and applied through overhead watering (10L of water used). Smoke water at a rate of 160 ml/punnet on the day of soil collection was applied.

A direct fire treatment occurred opportunistically from an ecological burn (4th October 2017) when the fire jumped containment lines and burnt part of the population. Flame height for the fire was an estimated 3 – 4 m with an unknown rate of spread, with all fuel under 20 mm consumed (fuel at 20 mm was scorched 5 mm in from

around the circumference) with an estimated 10 tonnes/ha of fuel.

Growth chambers modelled on the Enclosed Propagation Bed produced by Sage Horticulture (<https://www.sagehort.com.au/propagation-equipment/propagation-beds/propagationtrayheatmistenclosure>) used to grow the samples. The average temperature was 29.5°C (range: 21.2°C-35.1°C), 80% relative humidity and 13 hours of light per day from PSII globes.

Punnets were observed daily for 100 days to identify germinants to a floristic family.

Statistical analysis

A one-way ANOVA compares the control to the seed treatment as a response variable and the three treatments (control, smoke, or direct fire) as predictive variables. Minitab Express (Ver. 1.5.2.0) was used to identify relationships between data. EXSTAT Ecology (Addinsoft 2017) with R interface (R Development Core Team 2010) was used to complete ANOVA Analysis using germinant families, between treatments (fire, or smoke water or control), and monocotyledon and dicotyledon. Data collection occurred for 26 weeks with the statistical analysis performed on week counts of the seed treatments.

RESULTS AND DISCUSSION

Results

A total of 281 seeds germinated composed of 163 dicotyledons and 118 monocotyledons (Figure 1).

A single germinant of *Allocasuarina* sprouted in the fire treatment (Figure 2). Germinates of Cyperaceae and Myrtaceae were positively associated with treatments of fire or smoke (Figure 2). Other families that benefit from fire include the Leguminosae and to some extent, Dennstaedaceae. As observed, Dennstaedaceae can re-sprout after fire from underground rhizomes and may occur at lower relative abundances after the fire (Figure 2).

Smoke treated seeds had significantly higher germination rates ($F = 2.4499$, $df = 4$, $error = 116$, $P = 0.0009$) with an average of 10.83 ± 15.77 (S.D.) dicotyledons and 12.17 ± 11.74 (S.D.) monocotyledons. Fire treated seeds had intermediate germination levels an average of 10.50 ± 8.73 (S.D.) dicotyledons and 5.17 ± 2.23 (S.D.) monocotyledons. Control seeds had the lowest germination, with 5.67 ± 4.03 (S.D.) dicotyledons and 2.33 ± 1.97 (S.D.) monocotyledons (Figure 4). There was no significant difference in the average number of germinants of dicotyledons and monocotyledons in treatments exposed to fire ($\bar{x} = 3 \pm 0.7$ XCI, $P = 0.97$) or smoke ($P = 0.91$). The results produced nine dicotyledons families compared to monocotyledons composed of four Families (Figure 3).

The total number of dicotyledons germinated from fire and smoke was the same at the end of the twelve-week trial ($n = 65$).

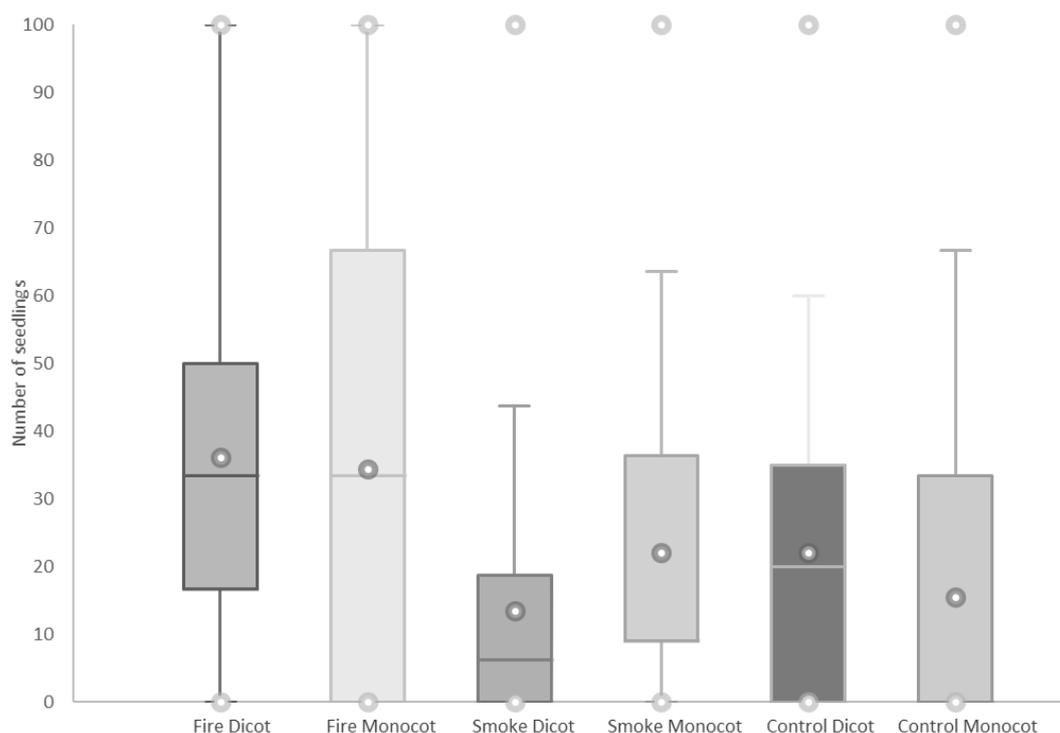


Figure 1. Frequency of germination of *A. robusta* by treatment (Dicot = dicotyledon, Monocot = monocotyledon)

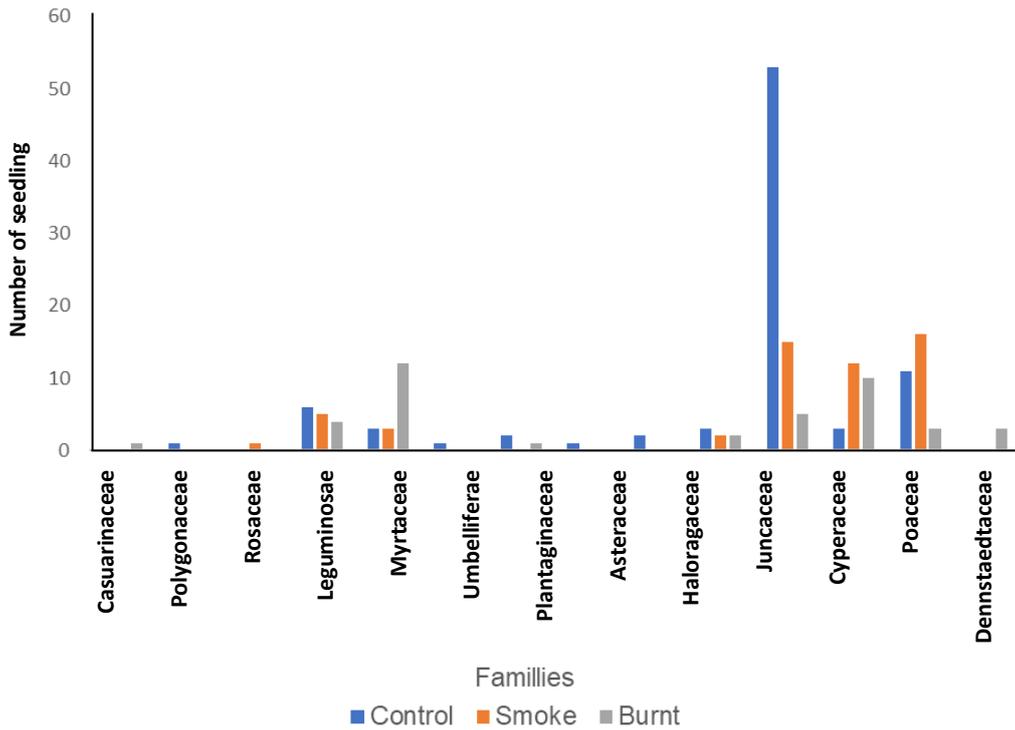


Figure 2. Family frequency of germination from soil samples

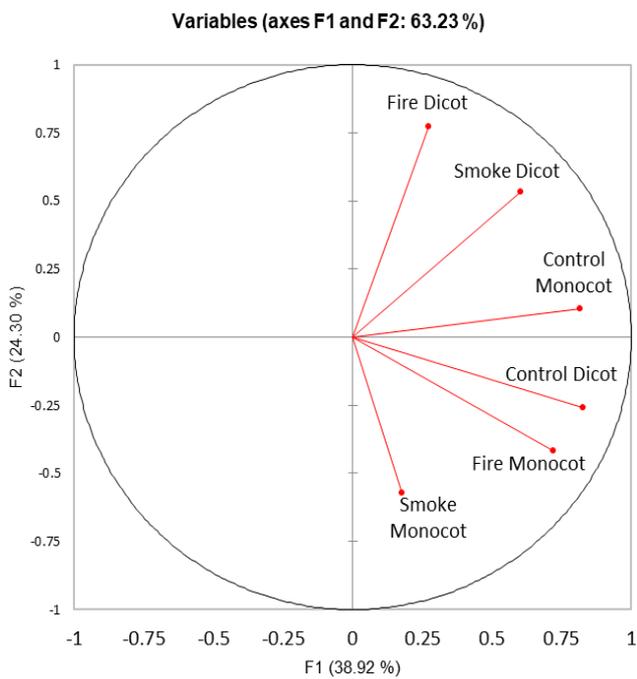


Figure 3. PCA plots of comparison between treatments (Dicot = dicotyledon Monocot = monocotyledon).

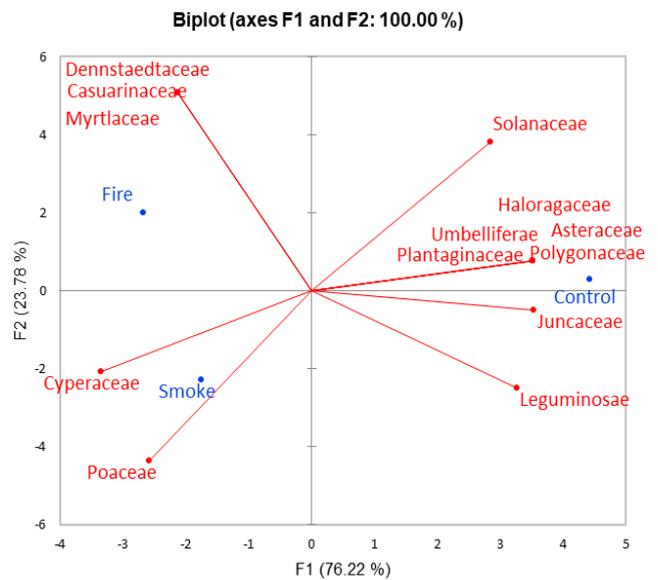


Figure 4: PCA plots of comparison between treatments and Families.

Discussion

The study aimed to test the effect of an ecological burn on *A. robusta* and determine whether collecting the latent soil seed bank is an adequate population recruitment tool. When exposed to fire and smoke, the trial indicated that

dicotyledons had the highest germination rates (Figure 3). Families that responded positively to the fire included Cyperaceae, Myrtaceae, and Juncaceae (Figure 2). The diversity of vegetation which resulted from the simulated disturbance event is not uncommon as Hodges et al. (2019)

describe that fire can maintain a rich diversity of forbs and graminoids. Hodges et al. (2019) identify that a misconception can occur that fire will promote vegetation to regenerate vegetatively but from seed recruitment.

From the pilot study, only a single *A. robusta* germination occurred. Therefore, the effect of fire on *A. robusta* is not apparent as single germination would not be conclusive for addressing the pilot study's aim. In contrast, an investigation involving removing the soil seed bank the germination of threatened flora increased (Řehouňková et al. 2020). In the investigation involving *A. robusta*, site-specific environmental characteristics may stimulate *A. robusta* seed to germination. From pot culture/controlled environment investigation fire may not be a significant driver of germination in *A. robusta* or, the samples may not have included viable *A. robusta* seeds. The single germination of *A. robusta* would fit within the perspective provided by Hodges et al. (2019) concerning seed recruitment not being favored by fire. Instead, vegetative regeneration is more frequent after a fire (Hodges et al. 2019). From the investigation, fire and smoke (Figure 4) indicate that some species will respond to burning. Zironi et al. (2019) explained that the results from their investigation produced an idiosyncratic response to fire. From the pilot study, fire and smoke responses may relate to the experimental design scale. From the investigation, the results support Zironi et al. (2019) by showing that fire resistance/tolerance can be an ecological advantage in landscapes shaped by fire.

The lack of *A. robusta* germinants demonstrates a need to identify what mechanism impeded germination. Understanding the lack of germination can relate to experimental design in how the treatment was applied consistently. Consistency and repeatability in the experimental design's pot culture could infer a particular result would occur under a specific condition. A specific result would not be unusual as Wills and Read (2002)'s investigation would support specific conditions that can elicit specific outcomes in regenerating communities when exposed to fire. Possible causes of reduced seed viability include age (Saverimuttu and Westoby 1996), inbreeding depression (Finlay et al. 2017) and competition (Cortina and Maestre 2005). The longevity of serotinous species can reduce viability overtime. In *A. robusta*, the aspect of dormancy related to the aggregate fruit could impact the species ability to recruit from seed. To break the dormancy as Hodges et al. (2019) postulates may not be related to smoke and heat, which may result in little or no impact on seed germination. In arid land species, the two-year-old seed has diminished seed viability (Gtinster 1994). However, the relationship to viability and longevity will vary with location and species, and we do not know how long *A. robusta* seeds are viable nor the age of the seeds in our study (Gtinster 1994; Ma et al. 2017). Competition from other flora and competition from graziers can also reduce seedling survival (Abbott 1984). Grazing can hamper natural recruitment if seedlings are a preferred feed. Further studies were advocated in the past on *A. robusta* to understand the germination process (Quarmby 2016). Quarmby (2016) identified that work is required to

understand natural recruitment, and it is plausible that the small populations of *A. robusta* may have reduced breeding fitness.

Previous investigations involving *Allocasuarina* have not focused on the relationship between germination, fire and environment (Abbott 1984, Gtinster 1994). *A. robusta* perceived as a serotinous regenerator, can challenge our concepts relating to a species interaction with its natural environment (Abbott 1984). Abbott (1984) study showed that a combination of factors could impact seedling survival either from browsing, the thickness of leaf litter or competition from neighboring plants. Vegetation communities shaped by fire can be affected by fire through the frequency of the fire. Defining or shaping a vegetation community by fire is not based solely on the presence and absence of fire. In an investigation by Le Breton et al. (2019), the inference of fire intensity related to the seed bank interpreted this as another form of selection within a community. As a fire increases in frequency or intensity perennial vegetation like *A. robusta* may not have reached a mature state to develop and store seed for release after a fire event Wills and Read (2002). Unlike Abbott (1984), these environmental conditions went untested, providing future research opportunities on *A. robusta*. Several other environmental factors relating to the physical environment could impact on the germination of seed following the release of seed, like Chick et al. (2018) identified the moisture and soil nutrient content the soil can play an essential role in the survival of a germinate. Compared to Wills and Read (2002), which identified that different fire intensity thresholds could result in different vegetation associations, a term used to describe this fire intensity on a seed is heat shock. Chick et al. (2018) shared the same hypothesis that fire could become a selective tool depending on fire intensity and frequency.

An environmental factor like heat shock to *A. robusta* fruit from the fire could form future studies. Heat shock in some species can range from 40°C to 80°C with the responses being variable between species and within a species (Ma et al. 2017; Dias et al. 2019). Heat shock is part of a physiological dormancy where the cue for germination is not from fire, but the generated heat (Ma et al. 2017; Luna 2020). The influence of heat shock on propagules or initiating the germination is related to several parameters, including the fire intensity, temperature, and spread rate (Dias et al. 2019; Zironi et al. 2019). The impact of fire on *A. robusta* will initiate the seed's release from the above-ground seed bank. Some species observed in a vegetation community respond favorably to heat shock effects (Dias et al. 2019). Seed release from the serotinous seeder like *A. robusta* will compete with seed stored in the soil seed bank that may be more competitive (Zironi et al. 2019). The results showed only a single *A. robusta* germination occurred, which indicated the possibility that heat shock could play an integral part in *A. robusta* seed recruitment (Dias et al. 2019; Le Breton et al. 2019). Zironi et al. (2019) describes that the fire's impact can change the soil properties, albeit only temporary, which may have selective quality on the germinants' survival. From the investigation conducted, changes in soil

properties may form an avenue for future investigation. The function of fire considered a factor that shapes Australian vegetation communities, but fire can cause the death of seeds even though others will survive (Zirondi et al. 2019).

The provision of heat shock from a fire and a simulated version of heat shock from boiling water and smoke water may elicit a different result. Ma et al. (2017) described the physiological response related to fire's direct effects on fruit. Compared to the heat shock undertaken by Alahakoon et al. (2020) investigation, which used a comparable method compared to the current investigation. Alahakoon et al. (2020) investigation supported the idea that fire would shape a vegetation community, but this was not replicated by either Luna (2020) investigation or the current investigation. In Luna (2020), the heat shock and the fire intensity related to the seed lens thickness. The results tend to lend themselves towards creating the perception that community that *A. robusta* is a part of a community not driven by fire (Figure 3). Alahakoon et al. (2020) investigation reported results where some serotinous species did not respond to a simulated fire and use smoke water as an alternative to fire. Like in Alahakoon et al. (2020), which identified further investigation is required to understand fire/smoke's role in simulating seed germination. The current investigation supports Alahakoon et al. (2020) conclusion, but in particular, the role of fire/smoke to initiate the germination of *A. robusta* requires further investigation. The importance of the interrelationships demonstrated by Cochrane (2020) investigation showed the importance of co-occurring species when changes in the environmental conditions occur. The single germination of *A. robusta* from the investigation can lead to the presumption that temperature may influence germination. The temperature in cooler winter rainfall areas of Australia can decrease germination if a sudden temperature increase occurs (Cochrane 2020). Making this presumption based on the evidence of single germination of *A. robusta* may seem somewhat unreliable.

From investigation *A. robusta* recruitment a species with woody aggregate fruit, demonstrating serotinous species' traits should positively correlate with fire. From the investigation, only a single germinant of *A. robusta* occurred, having a woody aggregate fruit is not the only trait that would define a species as fire tolerant. Tangney et al. (2020) identified that besides having fruit that protects the seed from fire is only part of the equation, and the other is survival at higher temperatures. Tangney et al. (2020) explain that the aggregate fruit's role is to protect the seed from lethal temperatures, allowing seed release to occur from the aggregate fruit. The aspect of the lethal temperatures to seed occurred in a previous investigation where the thickness of the seed lens dictated the survivability of a seed when exposed to fire (Herranz et al. 1998). The relationship between heat and germination between some serotinous species occurred through an investigation by Roeder et al. (2019). Roeder et al. (2019) and Luna (2020) establishes that the length of time a seed exposed to heat will reflect the seed survival. For instance, a fire with high intensity can reduce the survival of seed

woody aggregate capsules (Roeder et al. 2019). Tangney et al. (2020) explain that serotiny is composed of several traits to identify if a species is fire tolerant. Seeds with a thinner lens have lower survivorship from fire (Herranz et al. 1998; Luna 2020). The aggregate fruit may protect the *A. robusta* seed from fire as alternative to a thicker seed lens. In the investigation, the assumption made that seed released from sensing individuals. Based on the investigation from Herranz et al. (1998) the seed without the protection of the aggregate fruit may not survive.

Tangney et al. (2020) describe the physical traits (phenotypes) for classifying a species according to fire tolerance supports the review conducted by Lamont and Bellingham (2020) who describes that genotypes can be reflective of fire tolerance. (Lamont and Bellingham 2020) cites an example of the same species in different communities expressing different degrees of fire tolerance. The differences a single species can have in fire tolerance occurred through phenotype regulation from environmental stressors (Lamont and Bellingham 2020). From the current investigation, the lack of *A. robusta* germinants is partially supportive of the Lamont and Bellingham (2020) review of serotiny. Lamont and Bellingham (2020) do not discount the role of environmental factors contributing to communities that exhibit fire tolerance. For *A. robusta*, understanding the role of fire on the aggregate is considered necessary to determine the species' degree of serotiny. The concept of the degree of serotiny exhibited by species can be related to the review undertaken by Lamont and Bellingham (2020).

Lamont and Bellingham (2020) developed a model that indicates the degree of serotiny over time; the aspect of serotiny in *A. robusta* considered in Pearson (2020). From the investigation, a single seedling of *A. robusta* occurred, which raises several questions on the degree of serotiny in *A. robusta*. Determining the degree of serotiny *A. robusta* can occur through using Lamont and Bellingham (2020). The results from the current investigation would indicate that *A. robusta* is possibly not a serotinous species. Baskin and Baskin (2019) indicate that parental species influence seed germination to maintain the species existence. The paternal role of the parent indicated it might influence the genotype of the offspring. Extending the parental effect concept could form the species heritable traits (Lamont et al. 2020). The relationship that offspring and parents, according to Lamont et al. (2020) have been rarely studied. Lamont et al. (2020) demonstrate that serotiny is a heritable trait, but fire can be a selective tool for defining which species will form the community. The *A. robusta* samara seed would potentially move away from the parent plant by the wind. Řehouňková et al. (2020) described the targeted species seed, which moved into the clear areas had an increase in germination. The same concept needs testing with *A. robusta* to determine if germination increases in the parent plant's absence. The structure of the community would be reflective of the fire return interval. As the interval between a fire needs to be long enough for a species to germinate, reach a stage of maturity to set seed before the next fire (Lamont et al. 2020). The point made by Lamont et al. (2020) can be applied to *A. robusta* in as

far as understanding the parental effects on *A. robusta* seed recruitment and what level of serotiny does *A. robusta* have concerning fire.

Reflecting on the study's aim was to test the effect of an ecological burn on *A. robusta* by determining if latent soil seed bank supports seed recruitment of *A. robusta*. The results provided no conclusive answer; the study provides future avenues to consider the role of seed dormancy in *A. robusta*, the first step as Mackenzie et al. (2016) describes is to test and overcome the actual cues which will promote seed recruitment. Even though germination of seed regularly occurs in horticultural environments, the same may not be accurate for natural conditions (Mackenzie et al. 2016). From the pilot study, an underlying assumption occurred on competition between individuals in the seed bank. The assumption was that all individuals had an equal chance of germination and survival without competition. Catterall (2020) explains with a modified ecological community; the competition would be higher in the non-native species and the rudimental native species. The aspect of competition between seedlings can impact management strategies selected for regeneration for *A. robusta*. Catterall (2020) offers some possible strategies for reverting agriculture to a regenerated native community. Competition from other species would impact the *A. robusta* ability to regenerate, the other aspect discussed by Baskin and Baskin (2019) is the parent plant's role. Baskin and Baskin (2019) describe that maternal inflorescences can impact the soil's seed bank germination. The paternal relationship to the seed could occur through the seeds genotype (Baskin and Baskin 2019). These are avenues that would require further exploration to understand what may limit the natural seed recruitment of *A. robusta*.

Knowing where genetics would fit into these concepts can be seen as a possible area to investigate in the future. Understanding restoration practices and knowing how they could initiate natural seed recruitment strategies is vital (Catterall 2020). *A. robusta* position in the current landscape modified from agriculture (Bickford and Mackey 2004; Bickford et al. 2008). To restore fragmented communities of *A. robusta* a near undisturbed reference site required (Walpole et al. 2020). The reference site's purpose would indicate the degree of change in these sites and a level of resilience and responsiveness to facilitate recovery (Walpole et al. 2020). The difficulty in the restoration as Walpole et al. (2020) identified public perception of what the vegetation community was like before human disturbance can impact the project's success. Having a reference site to work from would be critical for the recovery of *A. robusta* as this would provide insight into how to simulate natural recruitment in the fragmented populations.

In conclusion, from the pilot study, it appears that *A. robusta* populations may not be recruiting to the population and would struggle to persist in the long term due to a lack of seed recruitment. A reliance on lignotubers for persistence may develop. The consideration of the role of lignotuber did not occur as part of the present study. However, long term survival requires seed recruitment as a necessary part of a future recruitment strategy. Serotinous

species like *A. robusta*, where the role of fire could trigger the natural recruitment of the next generation need further investigation. These future investigations should focus on cues needed for stimulating seed recruitment. Fire is part of the process; the management practices used need investigating further to ensure long-term population survival.

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