Post-fire demography of a dry eucalypt forest in the Midlands, Tasmania: A pilot study

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ABSTRACT

There have been many efforts to regenerate the threatened and declining dry eucalypt forests found within the Midlands of Tasmania. This pilot study was completed as part of a larger research project on eucalypt regeneration. Researchers need to know where recruits are most successful in order to appropriately place regeneration microsites. I have begun characterizing the baseline demography of a recently burnt remnant forest. I had two objectives: 1. to characterize the stand structure where recruits are successful, and 2. to describe where the recruits are within this structure.

Data on location, size, and life history stage of trees were collected in 12 study sites in a recently burnt, dry eucalypt forest. The data were analyzed using statistics on density, percent canopy cover, tree height, and basal area. A nearest neighbor analysis was executed to determine the effects of competition on the spatial distribution of *Eucalyptus spp.* Finally, an additive zone of influence analysis was used to relate the location of successful recruits to the overstorey adults.

Canopy coverage and the additive effect of zone of influence were the most important predictors of the location of successful recruits. Most successful recruits were found in study sites with relatively low canopy cover and in areas where the overlap between adult zones of influence was minimal. Compared to saplings, the location of lignotuberous sprouts was better correlated with these areas of minimal overlap. My findings suggest that while competition has an influence on spatial distribution, other underlying factors are also important in shaping stand structure and determining successful recruitment.

ISP Topic Codes: 614, 624, 608

Keywords: Recruitment, dry eucalypt forest, regeneration, demography

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FIGURES AND TABLES

ABBREVIATIONS & CLASSIFICATIONS

Abbreviations:

DBH: Diameter at breast height

GIS: Geographic Information System(s)

GPS: Global Positioning System

ZOI: Zone of Influence

N. site, N1-N4: Sites characterized as having no eucalypt seedlings and less than three eucalypt saplings.

Seed. site, Seed1 – Seed 4: Sites characterized as having at least one eucalypt seedling.

Sap. site, Sap1-Sap4: Sites characterized as having saplings, three or more eucalyt saplings and no eucalypt seedlings

Classifications:

Sprout: Has lignotuber, ≤1m tall, no woody growth

Sapling- Dependent on species:
- Non Eucalypt: < 2 m tall, woody growth
- Eucalypt: >1 m tall, < 10 cm DBH

Adult Tree- Dependent on species:
- Non Eucalypt: ≥ 2 m tall
- Eucalypt:: ≥ 10 cm DBH

I. INTRODUCTION

A. The state of dry eucalypt forests

1. Anthropogenic effects: For over 30, 000 years, humans have shaped the natural environment of Tasmania (McIntosh, Laffan, & Hewitt 2005). The dry eucalypt forests found within the Midlands are no exception to this paradigm. The reduction in dry eucalypt forests constitutes an extreme example of how land-use practices can degrade the environment. The dry eucalypt forests in the Midlands bioregion are "one of the most poorly reserved forest communities in Tasmania." Hawkins (2005)

The Midlands region was the second rural area in Australia to be settled by Australians before 1825 (Fenshan 1989). Forests were extensively cleared for agriculture and infrastructure (Fenshan 1989). Following the clearing of land, weed invasion and stock grazing continued, and still continue, to degrade the environment (Hawkins 2005). Today, over 83% of the native vegetation has been replaced by alternative land-use practices (Fenshan 1989). Global climate change has also contributed to dry eucalypt forest degradation. Hughes (2003). By increasing drought events and decreasing annual rainfall in Tasmania, the moisture stress, which dry eucalypt forests already experience, is amplified by climate change (Resource Planning and Development Commission 2003).

2. Importance of conservation and management: Scattered remnants of dry eucalypt forests still exist in the Midlands. Although low in number, these remnants have high economic, ecological, and, as will be shown in this study, scientific value. Sinden, Jones, and Fleming (1983) have described the economic value of eucalypt remnants in productive landscapes. They explain that conserving patches of forest can decrease erosion and provide shelter for stock. Without these patches, harvests are reduced and the land requires more intensive management. From an ecological standpoint, patches of forests provide habitat and food for native fauna, and ecosystems services such as reduced erosion (Yates and Hobbs 1997). The conservation of eucalypt forests, which sequester carbon, can also help slow global climate change (Private Forests Tasmania 2007).

Recognition of the importance of dry eucalypt forests has led to many regeneration efforts, including replanting trees and fencing programs designed to decrease grazing (Close & Davidson 2002). However, while Jurskis (2005) has shown that the suppression of fire is a significant cause of dry eucalypt forest decline, private land owners still regard fire as a disturbance which degrades the landscape. It is true that frequent high-intensity fires can have adverse effects on nutrient cycling and biodiversity (Conacher & Conacher 1995). However, when used correctly, controlled low-intensity fire may have the potential to rehabilitate and stabilize eucalypt forest structure to pre-colonial conditions (Jurskis 2005).

3. The role of fire: The aboriginal people in Tasmania started to use fire over 24,000 years ago in order to hunt and travel more efficiently (McIntosh, Laffan, & Hewitt 2005). Anthropogenic fires created woodland with an open structure and grassy understorey. (McIntosh, Laffan, and Hewitt 2005). Within the midlands, trees gradually adapted to a fire frequency of 8 to 25 (Davidson, pers. comm.. 2008) In order to maintain health in native forests, the fire regime to which that forest is adapted has to be maintained. The benefits of fire include greater seed dispersal through the more open vegetation (Vivian *et al.* 2008), temporary competitor removal (Yates, Hobbs, & Atkins 2000), stimulation of resprouting (Vivian *et al.* 2008), reduced litter biomass which can suppress seedling growth (Tolhurst *et al.* 1992), and the formation of seedling germination microsites (Bailey, Davidson & Close 2008). In summary, controlled low frequency fire can promote the success of *Eucalyptus spp.* recruits.

B. Providing a context: The larger study

1. Current Research: This pilot study was conducted for part of a larger research project on eucalypt regeneration conducted by Bailey (2007). The research project aims to identify the regeneration niche for eucalypts in dry eucalypt forests in the midlands . This knowledge can be used in restoration plantings so that suitable microsites are recreated in degraded landscapes (Bailey 2007). Thus far, Bailey has focused on the characterizing the recruitment niche of *Eucalyptus spp. (*Davidson, pers. comm. 2008).In an region with a predominantly low-intensity fire regime, eucalypt regeneration niches occur in spots where there is a local intense burn in large logs in the forest floor. As well as providing an ash bed of increased nutrient availability, these niches provide protection from climatic extremes, and a more consistent water supply (Bailey, Davidson & Close 2008). From a previous study on *Eucalyptus amygdalina*, Hawksins (2005) has concluded that available seedbed is hugely important in determining regeneration success in the Midlands. However, in another study on *E. delagatensis*, Battaglia & Reid (1993) found that a favorable microsite for seed germination is not necessarily a favorable site for seedling survival. Similarly, a favorable site for seedling survival may not be the same as a favorable site for recruit growth. Bailey and Davidson want to investigate where these germination microsites should be located within the forest structure in order to best assure that, during restoration in degraded forest, manually established microsites will yield successful recruits.

C. Overview of the pilot study

1. Purpose: The purpose of this study is to investigate the demography of a remnant dry eucalypt forest which was recently burnt. By studying a relatively healthy native forest, a baseline can be developed which degraded patches of eucalypts can be compared to. Just as in human populations, plant demography is the study of populations, and specifically the study of population age, density, and distribution (Merriam-Webster Online 2008). In this study, populations are sorted into two groups: non-eucalypt tree species and eucalypt species. Age can be difficult to determine in eucalypt species because lignotuberous sprouts can potentially persist on the forest floor for 50 years (Davidson, 2008, pers. comm). Therefore, as a substitute for age, I will use the life history stages of the trees. I recognize four stages: seedling, lignotuberous sprout, sapling, and adult tree (Williams & Woinarski 1994). In my study, living lignotuberous sprouts and saplings are considered to be successful recruits. Ultimately, I will use statistics on population density and the distribution of life history stages to explore the demography of the forest.

2. Objectives: My objectives were two fold:

1. Characterize the stand structure where recruits are successful.
2. Describe where the recruits are within this structure.

D. Stand Structure:

Stand structure is three dimensional: both lateral growth (understorey) and vertical growth (overstorey) need to be considered.

1. Understorey:

a. Non-eucalypt species: Often the understorey of a forest is disregarded when characterizing stand structure (McElhinny 2005). However, understorey species have been shown to have a significant influence on the success of seedlings. For example, Withers (1979) found that eucalypt seedlings were suppressed because the understorey *Casuarina spp.* reduced light penetration. Just like overstorey trees, understorey trees will also compete with recruits for nutrients and water (Canham, Lepage, & Coates 2004). Therefore, I hypothesize that as the density of understorey tree species decreases, the density of successful recruits will increase.

b. Eucalypt species: Eucalypt seedlings, lignotuberous sprouts, and saplings help to compose the understorey of the stand. Lignotuberous sprouts and saplings are both considered to be successful recruits because they are able to persist in the understorey and potentially become adults (Walters & Bell 2005). That is, an environment that is conducive to sapling growth should also be conducive to sprout growth. I hypothesize that the densities of three life history stages will increase or decrease concurrently.

2. Overstorey: Overstorey structure can be characterized using density of adult trees, % canopy coverage, % basal area, and total tree height (McElhinny 2005). Vivian *et al.* (2008) found that the density and basal area of adult trees had a strong negative correlation with seedling growth. They attributed this correlation to an increase in the level of resource competition by adult trees. The researchers also found that an increase in canopy coverage was correlated with a decrease in seedling height. Similarly, Withers (1979) found that an increase in shading caused an increase of mortality in shade-intolerant *Eucalyptus spp.* Finally, tree height has also been found to be relative to competitive advantage in eucalypts: Relatively taller trees have a greater capacity to photosynthesize and their growth will be limited by their ability to access water and nutrients (Basset and White 2000). Therefore, taller trees will suppress more recruits and cause a decrease in recruit density. All four overstorey structural attributes have been shown to be correlated with one another in hemlock and cedar (Canham, Lepage, & Coates 2004), and eucalypts (Bassett and White 2000). Therefore, I hypothesize that the density of successful recruits will increase as the overstorey structural attribute values decrease concurrently.

E. Spatial Analysis

1. Spatial Distribution: The spatial distribution of individuals within a population often reflects underlying processes of competition and mortality (Perry, Miller, & Enright

2006, Vacek & Lepps 1996). By delineating the spatial distributions of separate life history stages, it is possible to infer what underlying processes are controlling their distribution. Clumped distribution in seedlings succession often occurs because of seed dispersal by wind and the lack of density-dependent mortality (Myster & Pickett 1992). Furthermore, seedlings are expected to be clumped in any available nutrient- rich ashbed microsites which support germination (Bailey, Davidson & Close 2008). Lignotuberous sprouts are unique as they do not represent one cohort within the stand. Rather, sprouts can range in age from 1-50 years old (Davidson, pers. comm. 2008). As such, their distribution is determined by numerous disturbance events which can be random in time and space. Lignotuberous sprouts are expected to be randomly distributed due to these underlying random processes (Perry, Miller, & Enright 2006). Following accession to sapling, there is a shift to a regular distribution as an individual grows and competes in a greater area for nutrients, light, and water (Christensen 1977 and Sterner, Ribie, & Schatz 1986).

Such changes in spatial distribution were found in a demographic study of the savanna palm tree (Barot, Gignoux, & Menaut 1999). Researchers found that seedlings and juveniles were aggregated and attributed this aggregation to nutrient rich patches. Competition for these nutrients led to regularly distributed adults. Therefore, I hypothesize that *Eucalyptus spp.* will show a gradual progression from a clumped to regular distribution as it progresses from seedling to adult.

2. Zone of Influence: Assuming that adults will be regularly distributed due to the large amounts of area that they compete in for light, water, and nutrients, it then follows that if recruits are found within these areas they will have to compete with the adults. Gates and Westcott (1981) describe the area in which every individual competes for resources as the zone of influence (ZOI). Resource competition will occur when ZOIs overlap. However, the competition between successful understorey recruits and adults has been shown to be extremely asymmetric (Canham, Lepage, & Coates 2004). Overstorey trees exert a competitive force that can suppress lignotuberous sprouts and saplings and lead to recruit mortality (Bauer *et al.* 2002). Therefore, it is expected that successful recruits will not be found under the ZOI of adult trees (Basset and White 2000). While simple in theory, a standard method for defining the ZOI of individuals has not been established (Berger, Hildenbrandt, & Grimm 2002). For example, Alsweis and Duessen (2005) use a function of basal area raised to a species-defined constant, while Bi and Jurskis (1997) use a function of canopy radius. In this pilot study, I will define the radius of adult ZOIs as the tree height of individuals. Some foresters use the rule that light demanding trees, such as eucalypts, need to be a full tree height away from any mature tree in order to grow well (Farm Forest Line 2004). As already described, height can also determine competitive advantage, with taller trees having a larger resource base (Bassett and White 2000). Therefore, I hypothesize that successful recruits will be found at least one tree height away from adults- outside of the ZOIs of adults.

II. METHODS

A. Location: Tom Gibson Nature Reserve is located in the midlands of Tasmania, approximately 100 km south of Launceston. . In the last 20 years, the average rainfall in the Midlands has fallen by 12-15% from 550 mm to 490 mm (Bureau of Metiorology, 2008) rainfall in the 12 months prior to study was 400-600 mm (Fensham 1989) (Figure 1a).

Figure 1. Study area in Tom Gibson Reserve, Tasmania.
a.) Location of Tom Gibson Reserve within Tasmania. Map indicates annual rainfall from the period of May 2007 to April 2008 (Australian Bureau of Meteorology 2008).
b.) Tom Gibson Reserve with inset frame showing location of study area (Tasmanian Parks and Wildlife Service 2003).
c.) Study sites within the burned area of Tom Gibson Reserve.

The reserve is protected under the Regional Forest Agreement and is legally classified as an "indicative place" because it contains rare remnant midlands flora (Aussie Heritage 2007). These floras have been threatened by both past and current land-use practices and by global climate change. (Aussie Heritage 2007). It is characterized as a *Eucalyptus amygdalina* forest, and, as such, the tree community is made up of: *E. amygdalina* (black peppermint), *E. viminalis* (white gum), *Acacia spp.* (hop wattle), *Acacia dealbata* (silver wattle), *Allocasuarina littoralis* (black sheoak), *Allocasuarina monilifera* (necklace sheoak), *Banksia marginata* (silver banksias), and *Exocarpos cupressiformis* (common native cherry) (Dept. of Primary Industries and Water 2006). The reserve is also a habitat for rare and threatened fauna. Species include the *Bettongia_lesueur* (burrowing bettong), *Theca betulae* (brown hairstreak butterfly), *Vombatus ursinus* (common wombat), and *Perameles gunnii*, (eastern barred bandicoot) (Aussie Heritage 2007).

Controlled burns by the Tasmanian Parks and Wildlife Service were conducted in the southern region of the reserve in April 2003 (Tasmanian Parks and Wildlife Service 2007). Because the goal of my study was to investigate the post-fire demography of a tree community, where germination microsites would be found, the study area was located in the southeast corner of the burned region (Figure 1b).

B. Data Collection:

Our study area encompassed a mosaic of gaps types. In some gaps, seedlings but not saplings could be found. In others, saplings but not seedlings could be found. Finally, other sites were devoid of both seedlings and saplings. In order to characterize which structural attributes best support the growth of recruits, we decided to compare the demography of these three gap types. It was considered more efficient to focus data collection on 12 individual sites which would be indicative of tree community structure following disturbance. We collected data using Total Station surveying equipment at randomly selected sites from 16 – 21 April, 2008.

1. Stratified Random Sampling: Within a 150 m x 300 m study area containing many gaps, the three different types of gaps (described above) were identified. Four replicates of each gap type were then randomly sampled (as described below). Regions of the area that were close to a road were considered to be affected by an edge and were not characteristic of the interior of the forest (Bassett & White 2000).

Every gap was characterized as having: 1. eucalypt seedlings, or 2. eucalypt saplings, or 3. neither eucalypt seedlings nor saplings. Our visual survey encompassed an area with a ~20 m radius around the center of each gap. 1: *Seedling sites* were chosen if at least one seedling was found within the 20 m radius. Any sites which had both sapling and seedlings were characterized as seedling sites. 2: *Sapling sites* were chosen if there were three or more saplings and no seedlings. Saplings were defined as having a diameter <10 cm at breast height (DBH). It should be noted that the third sapling site did contain a seedling which we did not see during our visual survey. 3: *"Neither"* sites were chosen if there were less than three saplings and no seedlings.

In total, we identified 4 seedling sites, 12 sapling sites, and 9 neither sites. At each of these sites we took the GPS coordinates of the center of the gap. We then assigned each site a number and randomly selected 4 neither sites (hereby referred to as N1 – N4) and 4 sapling sites (herby referred to as Sap1-Sap4). All 4 seedling sites had to be used (hereby referred to as Seed1-Seed4). Our study areas were approximately 40 meters in diameter and could not overlap and repeat spatial data. Therefore, if two selected sites were within 40 meters of each other, we had to choose another site. The final 12 randomly selected study sites are plotted in Figure 1c (above).

2. Surveying: The boundary of the study site was defined by the second ring of adult trees around the gap. If the second ring of adult trees fell within a 20 m radius from the center of the gap, we still recorded all individuals within this 20 m radius. We stationed the surveying equipment in the center of gap where there was no canopy coverage. The position of this station was recorded using GPS coordinates when accuracy was at least ± 4 m.

Total Station Surveying equipment was used to record the location of every individual composing the tree community. In order to be efficient with time, the average position (barycenter) and dimensions of all non-eucalypt sapling and tree clumps were recorded. Clumps were defined as being of the same species and life history stage and as having continuous foliage. We recorded the number of individuals in randomly selected clumps in order to attain an estimate of non-eucalypt understorey density.

In addition to spatial data, we also recorded a series of demographic and structural data:

Non eucalypt species: The species name and life history stage were recorded for every individual. Non eucalypt saplings were defined as < 2 m tall and adults were defined as ≥ 2 m tall. *Eucalypt species:* Seedlings were distinguished from lignotuberous sprouts through the absence of a lignotuber. Lignotuberous sprouts were defined as being ≤1 m tall. Eucalypt saplings were defined as individuals >1 m tall and <10 cm DBH. The locations of both alive and dead saplings and adult trees were recorded. We also measured and recorded the diameter, height, and canopy radius of all adult eucalypt species. Height was estimated to the nearest 0.5 m using height poles. Canopy radius was recorded as the average lateral extent of foliage from the main stem. In order to simplify analysis, our method of recording canopy radius assumes that canopies were symmetrical and circular.

B. Analysis:

My analysis included thorough use of a geographic information system (GIS) through the ArcGIS program. GIS is powerful way to analyze spatial data which has attached attributes in order to classify data and establish relationships between layers of data (MacKey 1996). It also allowed me to output map figures which can help the reader visualize and explore trends in spatial data which may be elusive when looking at quantitative measures alone (Perry et al. 2006).

Point data taken from the total station was projected in WGS 1984, UTM Zone 55S. Prior to analyzing structural or spatial attributes of the tree community, I had to the area of each study site was found in order to correct for area and give a boundary for GIS to perform analysis in. The study boundary for each study site was created with a new polygon shapefile in GIS. I drew the polygon based on the following rules: 1. the polygon was convex; 2. the outermost trees were nodes of the polygon; 3. if lines connecting the nodes intercepted the 20 m radius circle, the study boundary was extended to the arc of the circle until another node (adult tree) outside of this circle could be snapped to. After completing a study boundary polygon, I calculated the area $^{(}m^{2)}$ through the calculate geometry function.

1. Structure:

*a. Under*storey*:* For non-eucalypt species, densities were estimated by multiplying the area of the clumps by the average number of species per clump, as discussed earlier. The densities of all individuals were corrected for area by dividing the calculated areas of respective study boundary polygons. I then multiplied densities (individuals/m^2) by the area of the generic circular study site with a radius of 20m (1256.6 m^2) to find the number of individuals per standard gap site. Doing so prevented me from presenting elusive data expressed in the number of individuals per square meter. The densities within each of the three study site types (N., Seed. and Sap.) were averaged and standard error was calculated using the equation $SE=SD/\sqrt{n}$, where n = the number of replicates (4). An ANOVA was employed to determine if a significant difference ($P<0.05$) existed between the density of species or life history stages between the three site types (N. Seed. and Sap.). If a significant difference did exist, I used a student t-test to test which of the three sites differed from one another.

b. ***Overstorey:*** To find percent canopy coverage, I summed the canopy areas and divided by the area of the respective study boundaries. I then calculated the mean canopy coverage per study site type. The same method was employed to find percent basal area and total tree height corrected for area (vertical m/m^2).

2. Spatial analysis

a. Spatial Distribution: In order to test for the spatial distribution of each individual life history stage, I had to separate the data into layers. To do so, I selected by attribute for data points which were distinguished as live seedlings, sprouts, saplings, and adult trees. I then used the nearest neighbor distance tool to determine the spatial distribution of the individual life history layers. The calculated distribution is based on the ratio of the observed average distance and the expected distance of every individual to its nearest neighbor as described by Clark and Evans (1954). It is important to note the necessity of defining a study area within the distance tool. With no defined area, the program analyses the points within the minimum area that encloses all the points. Therefore, individuals that may be clumped in a larger study area will appear to be uniform in the results (ERSI 2007). I defined the area by importing the study boundary polygons. Defining the study area also helped correct for the edge effect, where points outside the boundary will have fewer neighbors than those within the boundary (Perry et al. 2006).

b. Zone of Influence:

Preliminary analysis: To analyze where lignotuberous sprouts and saplings were located in respect to overstorey trees, I used a buffer analysis in GIS. Using the buffer tool, two buffers were created around every individual adult, with radii equal to the canopy radius and the tree height. The buffers were exported as tree height buffer and canopy buffer polygons. To find how many sprouts or saplings were within each buffer, I selected by location for sprouts and saplings that were contained by each buffer polygon. Because the number of individuals within the tree height buffer also included the number of individuals within the canopy radius buffer, I had to subtract the number of individuals within the canopy radius buffer from the total number in the tree height buffer. I did not include any individuals outside the study area because there was not ample context to support an evaluation. That is, these individuals might have been within the tree height or canopy buffers of adult trees that were not surveyed. Finally, I found the percent of individuals within each buffer across all 12 study sites. For clarification, an example of the buffer analysis methodology is shown in Figure 2.

Figure 2. Buffer analysis of N1. Every feature in the legend forms a separate layer. Sprouts and dead adults are points, while adult trees, buffers, and the study boundary are polygons. In this analysis, 8 sprouts are contained within tree height buffers, 3 within canopy buffers, and 1 outside the tree height buffer.

Preliminary results showed that most almost 80% of sprouts and saplings were within the tree height buffer polygon (Figure 2). The results allowed me to reject my original hypothesis that tree height defines the zone of influence (ZOI) radius and that saplings would be found outside this zone.

Figure 3. Percent of total eucalypt lignotuberous sprouts and saplings outside and within the buffers of adult eucalypt trees. Buffer radii were equal to the tree heights and canopy radii of individual adults. Sprouts N=347, Saplings N = 77.

In order to more accurately answer where sprouts and saplings were in relation to adult trees, I decided to explore the additive theory of the zone of influence. Bassett and White (2000) explain that in areas where ZOIs overlap, the effect of the influence will be additive. So, in areas with many overlapping ZOIs, regeneration growth will be reduced. Furthermore, because tree height did not correctly define the ZOI radius, I did a second additive analysis using the average ZOI radius of eucalypt trees in Tasmania as defined by Bi and Jurskis (1997): $\ln Z=1.21+0.65\ln CR$, where Z= ZOI radius and CR= canopy radius. I created a third buffer polygon layer with the buffer radius equal to Z, hereby referred to as the Bi & Jurskis buffer.

The additive analysis was executed using vector format. That is, my data remained in the form of polygons, lines, and points. I first added a field, influence value, to each buffer polygon. The result that few saplings were found within the canopy buffer (i.e. under the canopy) suggests that the canopy buffer has a stronger influence on recruits than the tree height buffer. Therefore, I assigned the influence value of 1 to the tree height and Bi & Jurskis buffers and a value of 2 to the canopy buffer. Because the vector data format cannot

not add overlapping influence values within the same layer, I had to divide overlapping tree height, Bi & Jurskis, and canopy buffer polygons into separate layers.

I then unioned the separated buffer polygons with the separated tree height or Bi & Jurskis buffer polygons. I added a field, total influence, to the union polygons which was equal to the sum of the influence values of all the separated buffers. For example, if two tree height buffers (influence value =1) overlapped, the total influence of the overlapping area would equal 2 and would be a separate polygon.

I decided to separate the total influence values into five classes, herby referred to as influence levels. I thought using five influence levels would be detailed enough to describe the effects of overlap. Every site differed in the maximum influence value, requiring that the data be classified with different intervals. I chose to classify using “natural jenks”. With this classification, the computer looks for natural breaks in the data and groups influence levels with similar frequencies together.

After classifying the data, I then had to create five more layers for each additive analysis which only included the total influence polygons of each influence level. With these five layers, I was able to select for sprouts and saplings that were contained by each influence level. Points not contained within any of the five layers were considered to be in a level of influence equal to zero. Like the earlier buffer analysis, I did not count any points outside of the study boundary.

Finally, the number of individual sprouts and saplings within each influence level was corrected for area. To do so, I first had to clip each influence level layer by using the study boundary as the clipping feature. Not doing so would underestimate the densities of recruits because many parts of the tree height and Bi & Jurskis buffers were outside the study boundary. I then used the calculate geometry tool to find the area of each influence level layer. From each of these layers I subtracted the basal area contained there within, as basal area represents an area where no other plant can exist (Berger, Hildenbrandt & Grimm 2002). I then divided the number of individuals by the area of the influence level layer to obtain the density of individuals within each influence level (individuals/m^2).

The mean and standard error of the density of individuals within each influence level were calculated across all 12 sites. I employed an ANOVA to determine if a significant difference ($P<0.05$) existed between the density of individuals in each influence level. When a significant difference did exist, I used a student t-test to test which of the five influence level densities differed from one another.

Ideally, I would have performed the above additive analysis using raster format. Raster is grid based and each cell within a grid has a value corresponding to a designated attribute. In this analysis, the attribute would be equal to the influence value (1 or 2) of the tree height, canopy, or Bi & Jurskis buffers. Then, one could overlay the buffer grids and sum the influence values of overlapping cells. However, I did not have the proper licenses to run raster analyses.

I created maps of the tree height additive analysis in ArcMap. I classified the maps using stretched classification, in which every total influence value is distinguished from the others. By distinguishing total influence *values,* the maps are not affected by the 5 semi-elusive classes of influence *levels.*

III. RESULTS

A. Structure

1. Understorey:

a. Non-Eucalypt Species: There was not a significant difference in the estimated densities of any species of non-eucalypt saplings or trees between all three site types (P>0.05) (Figures 4 and 5). *Banksia spp.* was the dominant non-eucalypt sapling species in all three site types (Figure 4). The dominant non-eucalypt tree species varied (Figure 5).

Figure 4. Estimates of mean densities (individuals/site, +SE) of non-eucalypt saplings in the three site types. Densities were corrected for area using a standardized circular site with a 20 m radius. **N**= 4.

Figure 5. Estimates of mean densities (individuals/site, +SE) of non-eucalypt trees in the three site types. Densities were corrected for area using a standardized circular site with a 20 m radius. **N**=4.

b. *Eucalypt Species:* There was no significant difference in the densities of lignotuberous sprouts in either species between sites (P>0.05) (Figures 6 and 7). The sap.

sites had significantly greater densities of saplings compared to both other site types (P<0.01) (Figures 6 and 7). *E. amygdalina* sprouts were the dominant life history stage and species within all sites (Figure 6). However, when only considering *E. viminalis*, there was more saplings than sprouts in the seed. and sap. sites (Figure 7). When comparing the two species, there were significantly less *E. viminalis* lignotuberous sprouts and saplings than those of *E. amygdalina* (P<0.05). (Figures 6 and 7). Furthermore, there were no *E. viminalis* seedlings in any site.

Figure 6: Mean densities (individuals/site, +SE) of *E. amygdalina* life history stages in the three site types. Densities were corrected for area using a standardized circular site with a 20 m radius. N=4.

Figure 7: Mean densities (individuals/site, +SE) of *E. viminalis* life history stages in the three site types. Densities were corrected for area using a standardized circular site with a 20 m radius. N=4.

2. Overstorey: There was no significant difference in the mean density of adult trees and the mean % basal area in the three site types (Table 1). The mean % canopy cover in the sap. sites was significantly less than in n.sites and seed. sites ($P<0.05$) (Table 1) However, the differences in mean canopy cover between n. sites and seed. sites were statistically insignificant (Table 1). There was also no significant difference in the mean tree height, expressed in vertical m/m^2, when comparing all three sites ($P=0.11$) (Table 1). Across all twelve sites, the average ratio of E. *amygdalina* to *E. viminalis* adult tree was equal to 21:1.

Table 1. Adult tree structural attributes: Mean density, % basal area, % canopy cover, and tree height (+SE) in each site type. N=4.

Site Type	Mean Density (trees/m^2)	Mean % Basal Area	Mean % Canopy Cover	Mean Tree Height (vertical m/m$^{2)}$
N.	0.0193 (0.0022)	0.381 (5.0E-4)	60.7 (6.5)	0.169 (3.1E-4)
Seed.	0.0236 (0.0056)	0.356 (1.5E-4)	61.6 (5.1)	0.200 (3.6E-4)
Sap.	0.0150 (0.0010)	0.304 (6.2E-4)	43.9 (5.9)	0.124 (1.7E-4)

B. Spatial Analysis

1. Spatial Distribution: With the exception of seedlings, the spatial distribution between all life-historey stages varied from site to site. The majority of sites had clustered lignotuberous sprouts (Table 2). With only one lignotuberous sprout, site N2 could not be analyzed. Saplings in all but 1 site were randomly distributed (Table 2). Half of the sites had adult trees that were regularly distributed (Table 2). Of the 6 sites with randomly distributed adult trees, 2 showed a strong trend towards being regularly distributed ($P<0.1$) There were not enough seedlings in any site to run a nearest neighbor analysis.

Table 2. Frequency counts of spatial distribution patterns in *Eucalyptus spp.* life history stages. Departure from a random distribution was considered significant when $P\leq0.05$. Frequencies were taken from across all study sites containing each life history form.

Life history Stage	**Clustered**	**Random**	**Regular**
Sprouts	7	4	0
Saplings	1	6	0
Adult Trees	0	6	6

2. Zone of Influence: In both the tree height and Bi & Jurskis analyses, sprouts had the highest densities outside of all zones of influence (level of influence =0) (Figure 8). The densities of sprouts decreased as the level of influence increased (Figure 8). ANOVA tests indicated that there was a strong significant difference in the mean densities of sprouts over all influence levels for both analysis types ($P<0.01$). However, T-tests for both analyses revealed that there was no statistically significant difference between densities of sprouts in levels of influence 0 and 1 and between densities in levels of influence 2 through 5 ($P>0.05$).

Figure 8. Mean densities (individuals/m^2) of lignotuberous sprouts within each influence level. Results of two analyses are shown: 1. Zone of influence defined by tree height, 2. Zone of influence defined by a function of canopy radius, as described by Bi and Jurskis (1997). N=12.

In both analyses types, saplings were densest outside of all zones of influence (influence level = 0) (Figure 9). Densities of saplings decreased up to influence level 4, in the tree height analysis, and influence level 2, in the Bi & Jurskis analysis, before increasing again (Figure 9). The tree height analysis also exhibited a sudden increase in the density of saplings in influence level 5. In the Bi and Jurskis analysis, there were 0 saplings in influence level 5 (Figure 9). ANOVA tests indicated that, in the *tree height* analysis, there was no significant difference in the mean densities of saplings across all influence levels. T-test confirmed that differences in densities in level 0, 1, 2 and 5 were statistically indifferent.

However, these densities were significantly greater than sapling densities in levels of influence 3 and 4. Oppositely, ANOVA tests indicated that, in the *Bi & Jurskis* analysis, there was a strong significant difference in the mean densities of saplings across all influence levels (P=0.017). However, similar to the sprouts, t-tests revealed that there was no statistically significant difference between densities of sprouts in levels of influence 0 and 1 and between densities in levels of influence 2 through 5 (P>0.05).

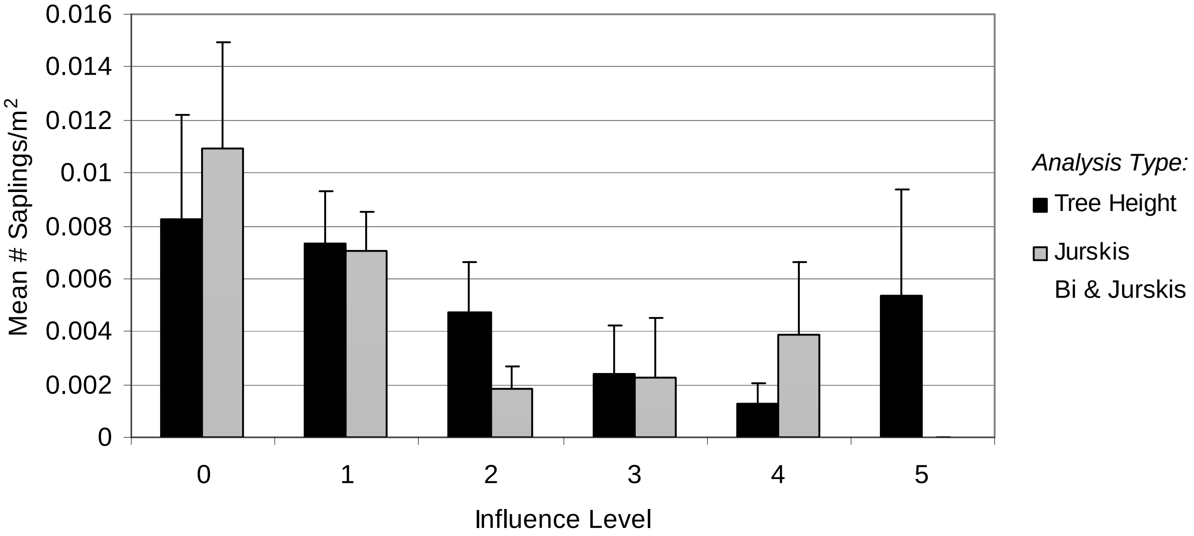

Figure 9. Mean densities (individuals/m^2) of saplings within each influence level. Results of two analyses are shown: 1. Zone of influence defined by tree height, 2. Zone of influence defined by a function of canopy radius, as described by Bi and Jurskis (1997) n=71.

The positions of recruits within tree height zones of influence are further clarified through examining figures 10, 11, and 12 (following pages). Areas that are darker have greater influence levels and contain fewer saplings and sprouts than areas which reflect lower influence levels. The figures also make it apparent that maximum total influences, which reflect number of overlaps, vary from site to site. The lowest maximum total influence is in Sap4 (Rd) while the highest maximum total influence is in N4 (Pd). The maps also illustrate the results of the analysis on overstorey structural attributes, especially mean tree height and densities. These maps will be further interpreted in the discussion.

Figure 10: Zone of influence (ZOI) spatial analysis maps for study sites N1 through N4. Total influence values are based a ZOI radius equal to tree height.

Figure 11: Zone of influence (ZOI) spatial analysis maps for study sites Seed1 through Seed4. Influence levels are based a ZOI radius equal to tree height.

Figure 12: Zone of influence (ZOI) spatial analysis maps for study sites Sap1 through Sap4. Total influence values are based a ZOI radius equal to tree height.

IV. DISCUSSION

A. Structure

1. Understorey:

a. *Non -eucalypt:* The results indicate that understorey species, both saplings and trees, do not have a statistically significant impact on recruit density (Figures 4 and 5). Therefore, I reject my hypothesis that a decrease in non-eucalypt understorey densities would correlate with an increase in successful recruit densities. This result, however, falsely implies that understorey species do not compete with or have a suppressive influence on eucalypts. Bowman & Kirkpatrick (1984) have found that interspecific competition for nutrient resources suppresses eucalypt species. Furthermore, Withers (1979) found that understorey *Casuarina* shaded the shade-intolerant eucalypt seedlings and was correlated with increased seedling mortality. Despite these negative influences, I speculate that the overstorey eucalypts had a larger influence on the recruits than the understorey non-eucalypts. Because these variables could not be separated in a field-based study, any influence that the understorey structure had on the sprouts was shadowed by that of the overstorey.

Interestingly, there was as positive correlation between the number of eucalypt saplings and the numbers of *Acacia* trees and *Banksia* trees and saplings. The greater presence of non-eucalypt individuals may be an indicator of an environment that is nutrient rich and suitable for eucalypt regeneration. The assumption that the presence of other tree species characterizes nutrient-rich patches was also made by Barot, Gignoux and Menaut (1999).

In addition to nutrient availability, the relative differences in the densities of species may be an indicator overstorey light penetration. Of the three non-eucalypt species composing the understorey, *Acacia* is the most shade tolerant (Withers 1979). *Banksia,* on the other hand, is more sun-loving (Withers 1979). The density of *Bankisa* saplings was much greater than that of *Acacia* in the sap. sites than the n. or seed. sites, suggesting more light is available in the sap. sites. This conclusion is further supported by the fact that the sap. sites supported the lowest densities *Acacaia* saplings, which are the most shade tolerant.

b. Eucalypt species: The result that most saplings were found in sap. site, and not seed. sites shows that seed. sites were less likely to yield saplings. Any sites with both saplings and seedlings were characterized as "seed." sites. Therefore, seed. sites could have potentially had an equal or greater amount of sapling than the "sap." sites. However, because this condition did not exist, the sites which contain seedling microsites probably are not the most conducive to sapling growth. This suggestion will be explored throughout the discussion.

Increased sapling density did not correlate positively with a significant increase in lignotuberous sprout density. Rather, any differences in the densitites of ligntuberous sprouts in each site were statistically insignificant. I therefore reject my hypothesis that densities of sprouts and saplings increase concurrently. This result demonstrates that some of the factors that limit sapling growth may not limit lignotuberous sprout survival. While eucalypt trees and saplings compete for nutrients, small sprouts have adequate carbohydrates storage in their lignotubers. This storage enables the sprouts to grow vigorously when the overstorey is removed (Walters & Bell 2005). Also, saplings may be more limited by nutrient and water distribution than lignotubers are. This was evidenced in a manipulative experiment by Walters, House and Doley (2005) which found that water and nutrient availability do not affect the growth of eucalypt lignotubers in Queensland. This hypothesis on resource limitation is further supported by the result that the lignotuberous sprouts were the dominant life history stage in all three sites. However, Fensham and Bowman (1992) also found that there were many more sprouts compared to saplings in a tropical eucalypt forest, and attributed this difference to termite damage, rather than resource availability. Their result demonstrates that implications about resource availability based on my results have to be made with caution. As will be discussed below, future studies should consider collecting information on nutrient levels in every site.

***2. Overstorey*:** Percent canopy cover was the only adult structural attribute which was significantly different between sites. As was expected, there was less canopy cover in the sites which supported sapling growth. When summarizing research by others, Bassett and White (2000) described the common result that there is an absence of regeneration directly below the crown of the tree in eucalypt species. This result can be explained by the low shade tolerance of eucalypts, as discussed earlier (Withers 1979). With increased canopy coverage in the seed. and n. sites, there is less area for recruits to survive. Also, the width of the eucalypt crown is usually correlated with (but not equal to) the lateral growth of the root system (Vacek and Lepps 1996). So, the difference in percent canopy cover may also reflect belowground competition, with sap. sites having the least competition. The result that the seed. sites had a significantly greater percent canopy coverage suggests that there may not be enough light penetration and too much underground competition for successful eucalypt recruitment.

Surprisingly, there was not a significant difference in the mean basal areas, densities, or total tree heights of adult trees in the three site types. Bassett and White (2000), studying eucalypts in Victoria, Vivian et. al (2008) studying *E. delagantesis,* and Hawkins (2005), studying *E. amygdalina,* found that a decrease in basal area correlated with an increase in regeneration. In these studies, basal area was decreased through tree removal, meaning that adult tree density was also reduced.

I can offer two possible explanations of why my results were not consistent with the above studies. First, the correlation between competitive influence and DBH is weaker for smaller trees than it is for larger trees. (Soares and Tome 1999) Therefore, the competitive influence of adult trees in sites with many small trees, such a Seed4 (figure 11d) is underestimated. Secondly, clumping reduces the influence adults have on understorey species because more area is free of competition (Basset and White 2000). The clumping of trees, even if not statistically significant, was not taken into account when analyzing the overstorey attributes. Therefore, tree density, basal area, and tree height may still be important factors which limit regeneration of eucalypts.

B. Spatial Analysis

1. Spatial distribution: Although the spatial distribution of life history stages varied, the results do show a trend that eucalypts become more regularly distributed as they grow. This result is consistent with my hypothesis. Although ArcGIS could not run analyses on seedlings, from visual inspection of the seed site maps (Figure 11), seedlings appear to be clustered. Hardner, Potts, and Gore (1998) related the clustering of seedlings to the method of seed dispersal. They found that in eucalypt trees, seeds were mainly distributed by the wind and gravity, which caused a clumped distribution. A better explanation can be offered by looking at where the seedlings are clustered. In most instances, clusters were found in the typical ashbed germination microsite (Bailey, Davidson & Close 2008). However, Seed3 showed a departure from this pattern, where seedlings were unexpectedly located near mounds in the northwest corner of the site (Figure 11c). I suspect that the mounds offer the same protection from climatic extremes and decrease in evaporation that can be found in the ashbed (Bailey, Davidson & Close 2008). Therefore, the distribution of the seedlings keeps with Close and Davidson's description (2001) of seedling *not* being "wheat field-like". Rather, they will be concentrated in areas which can support germination.

More lignotuberous sprouts were found to be clustered than I expected. A clustered pattern suggests that there is a lack in density dependent mortality brought about by competition (Myster and Pickett 1992). While the results do not agree with my hypothesis that lignotuberous sprouts are randomly distributed, they do reinforce a point made earlier: that lignotuberous sprouts are not as limited by nutrient or water availability as saplings are. Although they have extensive root systems (Walters and Bell 2005), there is probably not yet enough competition to thin the clumps. With an opening of canopy, sprouts are expected to grow vigorously into saplings (Walters and Bell 2005), at which point self thinning will occur.

Most saplings were randomly distributed, which supports my hypothesis. It should be noted that describing a spatial distribution as random does not mean that the process of generating the random distribution is, of itself, random (Perry *et al.* 2006) Rather, the result that saplings are randomly distributed possibly shows that there is increased competition and a move towards been regularly distributed.

Half of the adults were shown to be regularly distributed, another fourth showing a strong trend towards being distributed. Again, this supports my hypothesis. Adults have been shown to increase in regularity due to increased competition and defoliation, leading to the mortality of weaker competitors (Vacek and Lepps 1996).

2. Zone of Influence. The zone of influence (ZOI) analyses helped to confirm the above findings that intraspecific competition is important in determining the spatial patterning of eucalypts. In an improvement to other ZOI models, the additive analyses shows that as overlapping of zones of influence increase, the density of saplings and lignotuberous sprouts in these areas decreases. The objective of this study was not to analyze which analysis, the tree height buffer or Bi & Jurskis buffer, is more appropriate for eucalypts. Clearly, in contrast to my hypothesis, the zone of influence is not defined by tree height, because most individuals were located within tree height of at least one adult tree. However, my results show the two models act to reinforce each other. Therefore, I conclude that the number of overlaps (reflected in the level of influence), rather than the size of zone of influence, is important in determining where recruits will be located in relation to adult trees.

Lignotuberous sprouts were largely limited to levels of influence 0 and 1, and were just as likely to be in either of these zones. Although not statistically significant, my results show that there is a j curve decrease in the density of sprouts from influence levels 0 to 5. This finding is similar to findings of Hawkins (2005) who found that the number of seedlings decreased markedly closer to the trunk of adult trees. However, it should be noted that while Hawkins defined 'influence levels' by distance to the main stem, this study defined the influence level by describing the number of ZOI overlaps, which is not always related to the distance to the main stem. The low levels of influence may reflect less aboveground competition for light (Stage and Ledermann 2008) and belowground competition for water and nutrients (Casper and Jackson 1997).

The location of saplings in relation to levels of influence was more variable than the location of sprouts. The tree height analysis showed that saplings were as just likely to be in influence levels 0, 1, 2, or 5, but less likely to be in influence levels 3 or 4. This result slightly contrasts with the Bi and Jurskis analysis, where saplings were less likely to be in influence 2 through 5. Furthermore, both models showed that densities of saplings first decreased and then increased as the influence level increased.

The variation in sapling location may be due to several counterbalancing factors which determine spatial distribution. Because seeds are dependent on wind and gravity for distribution, the number of seedlings can decrease exponentially with distance from a parent tree (Myster and Pickett 1992). The opening of forest structure with fire allows wind to distribute seeds farther, but seeds are still more likely to be close to an adult. Casper, Schenk, and Jackson (2003) also found that ZOIs overlap in nutrient rich patches. So, while competition may be higher in these patches, it may be advantageous for saplings to become established there. As a final positive consequence, being within the zone of influence may protect seedlings from grass reinvasion (Hawkins 2005) which can suppress seedling growth (Wardle 1970). These factors which result in saplings growing close to an adult tree are counterbalanced by negative consequences of increased competition for water and nutrients (as described above), shading (Canham, Lepage, & Coates 2004) and allelopathy. Allelopathic chemicals, which can suppress understorey vegetation, are in higher concentrations closer to adult trees (May & Ash 1990). Allelopathy is a particularly relevant issue in drier climates, such as the midlands, because the leaf litter, containing the suppressive chemicals, is not decayed quickly (May and Ash 1990). As shown, there are many underlying and conflicting factors which structure may be reflective of and which ultimately determine where saplings are located within the forest. Interesting predictions can be made regarding the fate of the seedlings within the study sites of Tom Gibson Reserve. The results of the additive ZOI analyses suggest that the places best suited for seedling germination are not the ideal places for successful recruitment. The seedlings, found within the seed. sites, are likely to suffer from a lack of light availability and intense competition from multiple adult trees. These conditions can explain why seed. sites also had few successful recruits. I predict that the most successful seedlings will be those in Seed2. The spatial analysis map of Seed2 (Figure 11b) shows that there is less overlapping ZOIs and a greater area with a level of influence equal to zero. In fact, Seed2 map closely resembles the sites of Sap1-Sap4, which were able to support the greatest densities of saplings.

C. Other factors to consider

1. Browsing: Browsing has been shown to have an extensive influence on regeneration success (Hawkins 2005). In my field observations, many sites had burrows and holes, which are signs of animal activity. Interestingly, while I observed these burrows in the

n. sites and seed. sites, they were not obvious features of sap. sites. If the fauna browse close to these burrows, then browsing may explain why there were fewer successful recruits in the n. sites and seed. sites. The result that there was few *E. viminalis* saplings and no seedlings may also be attributed to browsing pressure. Brushtail possums, pademelons, and rabbits have been show to prefer *E. viminalis* over *E. amygdalina* (Hawkins 2005).

2. Anthropogenic disturbance: In some study sites, such as S3 and N2, signs of past human disturbance, in the forms of mounds, were evident. As I saw, the mounds supported the growth of saplings and seedlings. Disturbance probably upturned soil so that these mounds were more nutrient rich than the surrounding area. Close and Davidson (2002) explain that mounding also reduces moisture loss, which is a limiting resource in eucalypts. The presence of human disturbance could have skewed my results, resulting in greater densities of recruits than what would occur in a natural, undisturbed area.

3. Microtopography: Topography can affect drainage, moisture, and nutrient levels throughout a landscape (Enoki and Abe 2004). Nutrient levels are also impacted by nutrient levels, with soil on sunny aspects less leached of nutrients than soils on shady (southern) aspects (McIntosh *et al.* 2005). Leaching is of particular concern in dry forest, in which rainfall, which replenished nutrients losses, is limited (McIntosh *et al.* 2005). While I did not use topographic data in this analysis, total station does record minute changes in elevation. Therefore, the data can be used to discriminate if microtopography should be considered when establishing a microsite in a degraded remnant forest.

VI. CONCLUSION

A. Summary of Results:

This study has attempted to start characterizing the baseline demography of a recently burnt remnant forest. The baseline can be used to assess the health of degraded patches and determine their potential in supporting eucalypt recruits.

1. Characterize the stand structure where recruits are successful: I have found that relative to understorey structure, overstorey structure is more important in determining the distribution of successful recruits. Successful recruits were located in gaps which had less canopy coverage. Canopy coverage may be reflective of light availability and underground competition for moisture and light. Tree height, percent basal area, and adult tree density did not significantly correlate with the density of successful recruits but further spatial analysis indicated that, when integrated, these attributes are important in determining the location of recruits.

2. Describe where the recruits are within this structure: The spatial distribution of *Eucalypts spp.* indicates that the area of competition for resources increases as seedlings assess to adults. My results suggest that the competitive influence exerted by multiple adults has a suppressive effect on recruits. Sprouts are most likely to be found in areas of lower influence levels, in which less neighboring trees are competing for resources. The location of saplings relative to adults was more variable than that of lignotuberous sprouts, suggesting that factors other than resource competition are also important in determining successful recruitment.

B. Management implications

1. **The ideal placement of a microsite:** The study has shown that it is important to consider where germination microsites are manually established in order to better guarantee

successful recruitment. In interest of simplicity, I would suggest that the microsite be placed within the following three constraints: 1.In an area where canopy coverage is <50%. 2. Outside the area of any adult canopy. 3. Away from tall neighboring trees with large canopies. My results also show that it is not necessarily wise to choose a location which has a lack of understorey species in the interest of reducing competition with a recruit. In fact, a presence of non-eucalypt understorey species may be an indicator of resource availability.

2. The role of fire: Although the entire study area had undergone a controlled burn 5 years ago, my results show that fire does not affect a landscape in a uniform manner. My three study site types exemplify the mosaic of conditions in the forest, where some gaps have very little if any successful recruits, while other gaps support a greater amount of regeneration. Interestingly, while it can be assumed that the seed. sites were the locations of the most severe fire, as is evidenced by an ashbed, they were not the sites which supported the most lignotuberous sprouts, which can regenerate quickly after a fire. Instead, the sap. sites had greater densities of saplings and lignotuberous sprouts. In this study, fire was shown to offer the benefits of increased seed dispersal and the creation of a suitable germination microsite. These benefits may be replicable without the use of fire. For example, hand sowing seedlings near appropriately placed protective mounds may produce successful regeneration. This is not to suggest that the use of fire as a management tool should be neglected, but that other methods may be used alongside fire to guarantee the best rehabilitation of degraded dry eucalypt remnants.

C. Lessons from the pilot study

I recognize that many variables related to demography were explored in this study. There are several changes I would make to future demographic studies to ensure that they are more effective and reasonable to apply on a larger scale.

1. Under**storey*****:*** While non-eucalypt understorey structure may affect regeneration, it has been shown to be secondary to the effects of overstorey structure. Given that collecting this data took a huge amount of additional time and effort, I recommend that non-eucalypt understorey structure is taken note of but not be included in spatial data collection.

2. *Simplifications:*

a. Canopy: There is no doubt that the accuracy of the ZOI additive analysis could be improved by a more realistic representation of crown shape. However, this method is likely to add significant burden in the field without a significant gain in predictions of where recruits are located. If more accurate data on canopy coverage is required, I recommend using satellite imagery.

b. ZOI: While I think a more accurate way of defining the ZOI radius would be useful, it is not as important as more accurately delineating the amount of influence within the ZOI. Berger, Hildenbrandt & Grimm (2002) have shown that the amount of influence that a tree exerts decreases exponentially from the stem. In the pilot study, I started to show this decrease with a graduated system where the influence value of the canopy buffer equaled 2 and the tree height buffer equaled 1. However, tools in GIS, such as the multiple ring buffer or raster analysis, can be easily implemented to better represent the exponential decrease in influence.

2. Study area: In this study I chose to survey 12 separate sites. Doing so allowed me to characterize and compare three site types in an efficient manner. However, there were several drawbacks. First, many individuals had to be excluded from spatial analysis because they did not have enough spatial context to accurately describe their position within the forest. Secondly, smaller study sites also limited the number of individuals within each site to a level in which Ripley's K analysis, a more effective way to analyze spatial distributions , could not be executed (Perry et al. 2006). I recommend that 2 or 3 larger study areas be chosen and analyzed using spatial analyses tools in ArcGIS or a similar program.

D. Future Research

Our understanding of eucalypt regeneration may benefit from studying how potential recruits are impacted by browsing, underground competition, and moisture and nutrient resource availability. Browsing may impact sprout and sapling success, with the fewest successful recruits found in areas which evidenced the presence of several browsing species. Underground competition also needs to be considered and related to above ground overstorey attributes in a dry eucalypt forest. Then, a more appropriate ZOI can then be developed which will help pinpoint areas that will be favorable to eucalypt regeneration. Finally, studying moisture and nutrient availability is important in understanding the underlying causes of spatial distribution. It would be interesting to know if areas with the greatest resource availability support more successful saplings, or if competition from adults outweighs the benefits of growing in these areas.

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