Bol. Mus. Nac. Hist. Nat. Parag. Vol. 21, nº 1 (Jun. 2017): 5-26

GROUND-DWELLING ANT SPECIES COMPOSITION AFTER DIFFERENT PRESCRIBED FIRE TREATMENTS IN THE WOMBAT STATE FOREST, SOUTHEAST AUSTRALIA

COMPOSICION DE ESPECIES DE HORMIGAS TERRESTRES LUEGO DE VARIADOS TRATAMIENTOS DE QUEMA PRESCRITA EN EL WOMBAT STATE FOREST DEL SURESTE DE AUSTRALIA

Claus Brehm*

*Cocue Guazú, Areguá, PY, clausbrehm@gmail.com

Abstract.- Invertebrates are important indicators of ecosystem disturbances. Within this group ants have been studied intensively. In this study ants were collected in a total of 75 sampling sites in the Wombat Forest in southeastern Victoria, also known as the FESA study or Fire Effect Sample Areas. There 5 prescribed burning treatments are being analyzed to measure the impact of each treatment on the environment. These treatments consist in different frequency and seasonality of the fires. In 2012 litter sampling was made to collect invertebrates to analyze the taxa and species composition, abundance and richness. This leaded to the identification of the impact of different prescribed fire treatments on insect communities. Of these invertebrates, a total of 3515 ants have been sampled and identified, representing 31 morphospecies, 22 genera and belonging to five subfamilies. The collected ants represent 7 functional groups. The most abundant was the Opportunist group, with 65 % of the total, followed by the Dominant Dolichoderinae group with 11.7%. *Rhytidonopera* was the most abundant species, with 46.1 % of all collected ants and followed by *Paraparatrechina* with 18.7% of the total. This study analyses if there was an impact of ant species composition after nearly 30 years of different fire treatments in the area. Parallel to the invertebrate sampling, 41 environmental variables were measured at the sample sites. These variables, related to geographic aspects, soil and litter were analyzed in relation to the fire treatments and the ant species richness and composition. With the statistical analysis it was determined that no significant impact of abundance or species richness was caused by the different prescribed burning treatments. Neither a change in functional groups was found, but a shift of species within the Opportunist functional group, caused by the seasonality of the fires.

Key words: *ants, functional groups, fire treatments, environmental variables*

Resumen.- Los invertebrados son importantes indicadores de disturbios en ecosistemas terrestres. Dentro de este grupo las hormigas han sido estudiadas de manera intensiva. En este estudio, hormigas fueron colectadas en 75 sitios de muestreo dentro de lo que es el Wombat Forest en el sureste de Victoria, también conocido como área de estudio FESA por sus siglas en inglés de áreas de estudio de efecto de quemas prescriptas. Allí, 5 tratamientos diferentes de quemas prescriptas son analizados para medir el impacto que tiene cada tratamiento sobre el ambiente. Estos tratamientos consisten en quemas prescriptas con diferentes frecuencias como estacionalidades. En el año 2012 se realizó un muestreo de la hojarasca para la recolección de los invertebrados y así identificar los taxones presentes, la composición de especies así como la abundancia y riqueza de especies. Esto llevó a la identificación de los impactos que los diferentes tratamientos tuvieron sobre las comunidades de insectos. De estos invertebrados, un total de 3515 hormigas fueron recolectadas e identificadas, representando a 31 morfo especies, 22 géneros, pertenecientes a 5 subfamilias. Las hormigas recolectadas representan a 7 grupos funcionales. De estos, el más abundante fue el grupo de las oportunistas, con un 65% del total, seguido de las Dolichoderinae dominantes, con un 11,7 %. La especie más abundante fue *Rhytidonopera* con 46,1% del total, seguido de *Paraparatrechina*, con un 18,7%. Este estudio analiza si hubo algún impacto en la composición de especies luego de 30 años de los diferentes tratamientos de quema prescripta en el área. También fueron medidas 41 variables ambientales en los sitios de muestreo como pendiente, suelo y hojarasca. Estos fueron analizados en relación a los tratamientos así como a la riqueza y a la composición de especies de hormigas encontradas. Con un análisis estadístico se pudo determinar que los diferentes tratamientos de quema prescripta no tuvieron un impacto significativo sobre la abundancia o riqueza de especies de hormigas. Tampoco se encontró un cambio en los grupos funcionales, sólo un intercambio de especies dentro del grupo de las oportunistas, causado por la estacionalidad de los fuegos.

Palabras clave: *hormigas, grupos funcionales, quemas prescriptas, variables ambientales*

Fire hazard is increasing worldwide, caused by climate change or other long-term geological processes we still don’t fully understand (Clark *et al.,* 2014). This increase is even more pronounced in Australia (Hasson *et al.,* 2009). Australia is known as one of the most fire prone

Recibido: 28.iii.2017 | Aceptado: 19.vi.2017

countries in the world (Bradstock *et al.,* 2002), with the State of Victoria, in the southeast, especially susceptible to intense and extensive wildfires (Luke & McArthur, 1978). Since the year 2000 at least 3 high intensity wildfires occurred in Victoria, burning more than 3,000,000 hectares of land, countless goods and properties and causing the loss of almost 200 human lives (Attiwill & Adams, 2013). Prescribed burning is increasingly being considered as a solution for the reduction of available fuel and consequently decreasing the potential impact of a natural wildfire event. This technique involves burning of litter and woody debris during low fire hazard periods of the year, mainly in autumn or spring. This because the risk of uncontrolled spread is lower in this seasons than during hot and dry weather conditions in summer. However, with the increase of fire hazard, the demand of prescribed fires is rising as well.

Since the 1950's the control of fuel availability started to be considered as essential to control this risk and after devastating fires in the 70's and 80's the government decided to apply more prescribed burning. After the Royal Commission Report of the 2009 fires in Victoria a target was set to burn at least 5% of available public land every year. With the increase of fire risk days due the factors mentioned above, the amount of available days for making prescribed burnings is decreasing. Therefore, to reach this goal, fires will have to be lit more frequently and in more than one season.

The fire regime is the pattern of fires in time and space (Krebs *et al.,* 2010), comprising the frequency, seasonality and intensity of fire. The frequency is determined by how many fires over a certain period of time occur on the same spot and has an impact on the habitat conditions of the area. Some plants are susceptible to fire frequency, because if fires occur more often than the time it takes the plants to generate viable seeds, the species will most probably become locally extinct, if it only regenerates from seeds. Seasonality of the prescribed fire is other aspect that may have an impact on the habitat conditions of an area. In southern Victoria, fires ignited in spring will be followed by drier and warmer conditions, whereas wetter and cooler conditions will follow autumn fires. The seasonality may also affect the intensity of a fire. In spring the fuel is normally wet and humidity is high after the winter, but in autumn the fuel is dry and air humidity tends to be low, which may result in a higher intensity of the fire in that season. The seasonality will therefore influence both, fire severity and the post-fire environment.

To analyze the impact of frequency and seasonality of prescribed fires, in 1984 the Victorian Forest Commission established a research site in the Wombat Forest, a mixed eucalypt foothill forest in southeastern Victoria. Since 1985 the impact of different fire regimes on components such as vegetation, understory, tree growth, invertebrates, birds, mammals and others has been evaluated periodically (Department of Sustainability and Environment, 2003).

Invertebrates dominate terrestrial ecosystems (Barrow *et al.,* 2007) and are important for many ecosystem functions, especially in the litter. Their interaction with fungi, bacteria, animals and plants is of basic importance for the functioning of the ecosystems. Breaking down organic matter, improving physical and chemical properties of the soil and so creating an optimum habitat for vegetation are some of their mayor contributions (York *et al.,* 2012).

Within the invertebrates, ants again are essential for nutrient cycling and for the manipulation of the chemical and structural properties of the soil due their activities (Höllerdobler & Wilson, 1990, Andersen 1991a, Andersen *et al.,* 2005). Many plants, invertebrates and vertebrates have evolved to form relationships with certain ant species and rely on their presence (Greenslade, 1979). Ants are also the most diverse group of social insects with more than 12.500 described species worldwide, just the half of the estimated total of ant species (Del Toro *et al.,* 2012). It is important to study their response to fire, as they have been shown to be very effective for monitoring the condition of ecosystems (Underwood & Fisher, 2006) and the recovery of perturbed ecosystems after fire, mining or land clearing (Jackson & Fox, 1996).

Myrmecochory, which is the dispersal of seeds by ants, occurs through the presence of elaisosomes, which are nutrient rich parts of the seed not required for the germination. These tissues are eaten by some ant species and therefore they transport the seeds (Parr *et al.,* 2007). Beaumont *et al.* (2013) demonstrated that fires have an impact on this important ecosystem process.

Fire may be beneficial to ant communities because of provoked seed fall, mobilization of nutrients and clearing of the landscape, which enhance foraging (Jackson & Fox, 1996). Also by modifying structure of habitat, which influences the diversity of ants (York, 1994). Nevertheless some species or functional groups may be affected negatively by an increase of fire frequency or a change in seasonality (Andersen *et al.,* 2012). Impacts of fires on ant communities are normally indirect, through the modification of the habitat with increased predation risk due to simplified habitat structure and resource availability, not because of direct mortality. Even with high intensity fires, most of the ant species retreat fast to their nests under the ground where they are not affected by the fire (Andersen, 1991b, Andersen *et al.,* 2012). Very few ant species live in trees like *Oecophylla* or above the ground like *Podomyrma* or *Camponotus* (Greenslade, 1979). Andersen *et al.* (2005) observed a very high impact of fire frequency on species composition of arboreal ants.

The impact of fires on ant communities has been studied extensively across the Australian landscape, (Beaumont *et al*., 2012, Manwaring *et al*., 2014, Gosper *et al.,* 2015, and many others), but not many of those studies reached the morphospecies level and include the functional groups. Identifying the functional groups of ants with the Andersen system (Andersen, 1995) is other important component of research because each of these groups has a different function in the ecosystem. Some are predators, other disperse seeds or contribute in other way.

This is still a significant gap of knowledge and could be attributed to the fact that many ant species in Australia have not been described yet (Shattuck, 1998; Andersen, 1991b). Exceptions are the studies made by Greenslade (1986) in South Australia and Andersen in the northern Territory, where species levels and functional groups were essential part of the data collected and analyzed (Andersen, 1991b). Also York (2000), Manwaring *et al.* (2014), Andrew *et al.* (2000), Gunawardene & Majer (2005), Parr & Andersen (2008) and few others included functional group analysis in their research. But it is still not an essential component of ant community composition researches.

In an earlier study, York (2014) observed that there was no significant impact on ant abundance by altered fire frequency or seasonality. In this study I investigate whether there is a change in the functional group composition of ants across the different treatments or a change in species composition within the functional groups. The aim of this study is to compare ant species assemblages across the different fire treatments in the FESA study area and to establish if there these effects are caused by fire-related changes in the environment.

METHODS

Site description

The Fire Ecology Study Area (FESA) was established in 1985 incorporating five ‘Areas’ within a 25 km radius; located in the Wombat State Forest, in the State of Victoria, in southeast Australia (Figure 1).

Soil chemistry, tree growth, bark thickness, impact on understory vegetation, fuel dynamics and many other related topics have been studied (Collett & Neumann, 2003).

Geology of the area is Ordovician rock from sedimentary origin. Topography is flat to hilly with slopes from 0 to 21 degrees with elevation

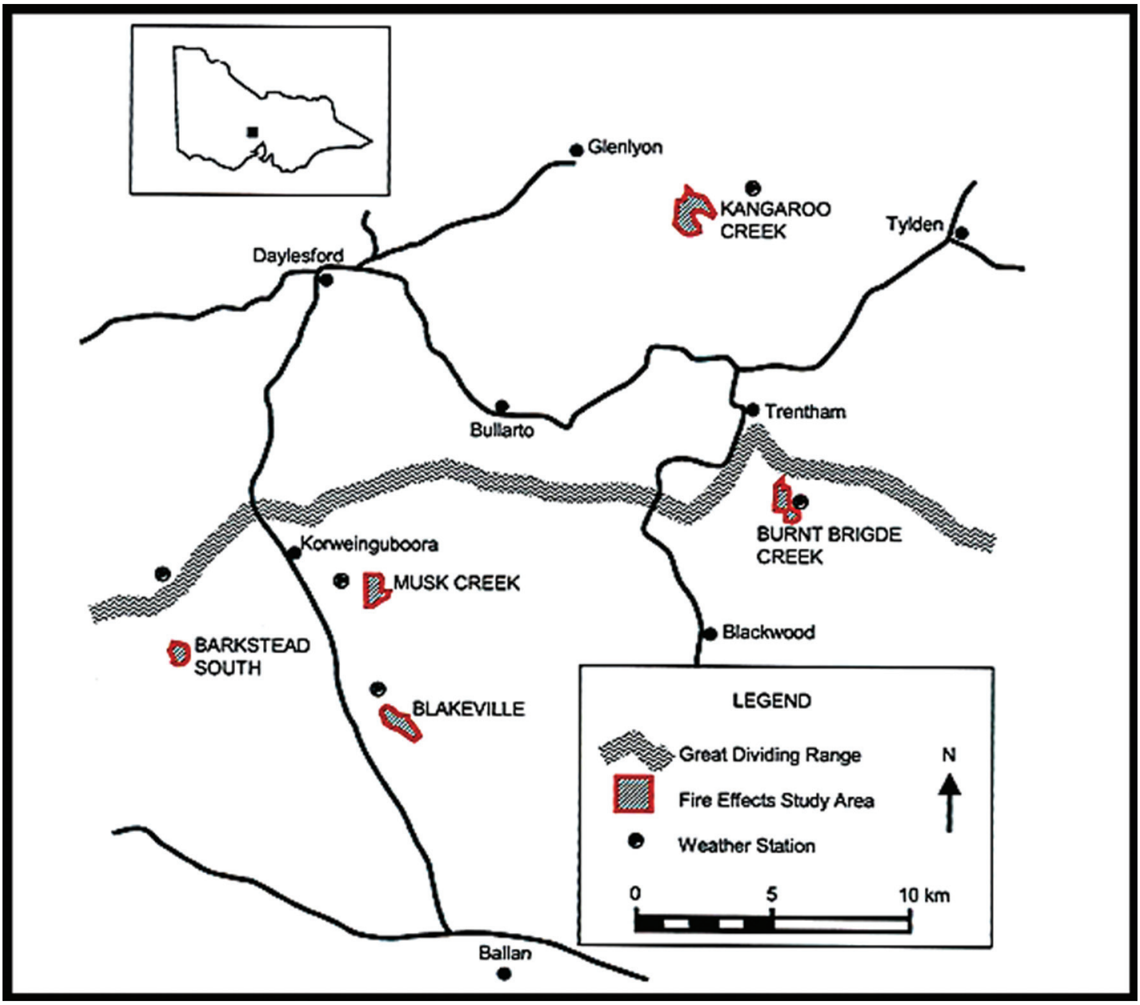

Figure 1. Study area with the 5 FESA sites (source Shrestha *et al.,* 2012).

ranging between 590 and 760 m. a.s.l. The size of the study areas ranges between 19 and 128 hectares (Table 1). Precipitation is on average between 814 to 901 mm per year and the climate is temperate with average temperatures between 2 to 24 degrees Celsius (Tolhurst & Flinn, 1992). Vegetation in the area is classified as tall open forest, with dominant species like Messmate (*Eucalyptus obliqua)*, Candlebark, (*Eucalyptus rubida)* and Narrow Leaf Peppermint (*Eucalyptus radiata).* Understorey is composed of Acacias, shrubs and grasses (York, 2014). Using a randomized block design, four prescribed fire treatments were established in each of the areas. Two different frequencies, at 3 and 10 years and with two seasonalities each, in autumn and in spring. Also one control site, which is kept without fire, resulting in total 4 treatments and one control site. The following designation will be used for each treatment (S3) for spring with high frequency, (S10) for spring with low frequency, (C) for the control site, (A3) for autumn with high frequency and (A10) for autumn with low frequency (Figure 2). For information about when fires were lit since the beginning of the FESA research see Table 1.

Having 5 sites and 5 treatments gives a total of 25 treatment areas (Figure 2). Although the study in the FESA project has been going on now for more than 30 years, no other sampling

Table 1. FESA sites with site conditions and fire interval data (modified from Bennett *et al.,* 2013).

	Areas				
	Blakeville	**Barkstead**	**Musk Creek**	**Burnt Bridge**	**Kangaroo Creek**
Latitude/Longitude	37°31´S, 144°05´E	37°29´S, 144°05´E	37°28´S, 144°10´E	37°25´S, 144°20´E	37°19´S, 144°18´E
Elevation (m, above sea level)	590-665	635-650	620-720	710-760	615-645
Slope (degrees)	1 to 13	0 to 4	1 to 16	0 to 15	0 to 21
Aspect (degrees)	130-295	120-315	40-310	30-270	0-340
Mean annual rainfall (mm)	871	901	856	896	814
Mean monthly max temp. (°C)	9 to 24	8 to 23	10 to 24	7 to 22	8 to 24
Mean monthly min temp. (°C)	2 to 10	2 to 10	3 to 11	2 to 11	3 to 12
Tree mean basal area (m2/ha)	43	31	29	43	42
Tree mean height (m)	26	28	25	26	23
Last thinning	1964	1979	1974	1977	1975
Last wildfire	1935	1931	1974	1953	1944
Total experimental area (ha)	81	19	78	62	128
Mean fire intervals (yrs) A3	3.0 (6, 1987-2007)	4.0 (5, 1987-2007)	4.0 (6, 1987-2008)	5.7 (4, 1987-2007)	3.4 (6, 1987-2009)
Mean fire intervals (yrs) A10	9.5 (3, 1987-2008)	9.0 (3, 1987-2007)	16.0 (2, 1987-2004)	16.0 (2, 1987-2004)	9.0 (3, 1987-2007)
Mean fire intervals (yrs) S3	3.6 (6, 1985-2008)	3.6 (6, 1985-2005)	2.7 (6, 1986-2005)	2.7 (7, 1986-2008)	2.8 (7, 1985-2008)
Mean fire intervals (yrs) S10	9.0 (3, 1985-2005)	9.0 (3, 1985-2005)	8.5 (3, 1986-2005)	8.5 (3, 1986-2005)	9.0 (3, 1985-2005)

data for ants was available than the set used for this research, so this has to be considered as a snap shot of the current situation, as a long term accumulative effect of the treatments on the study area. The control sites provide data for the long unburned conditions in contrast to the different treatments.

Sampling methods

In 2012 leaf litter samples were taken in each of these sites with 3 repetitions to represent the topographic variability, on the ridge, slope and gully, resulting in overall 75 sample sites, using a standard sampling protocol by York (2012) see Annex 1. The topographic variability was not considered as a factor in the statistical analysis because there was no replication, but captured within-site variability. In each of this sample sites twenty 2000cm^3 containers of surface litter were collected from 18 meters long and 2 meter wide transects established on each sample site.

After the collection of the litter samples

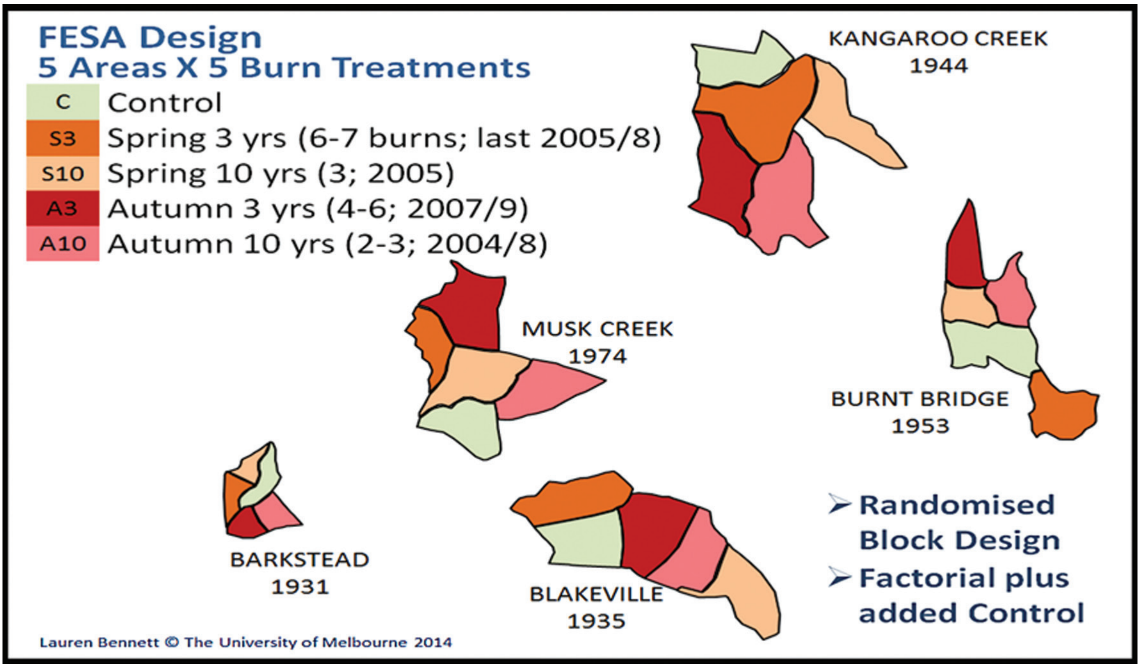

Figure 2. FESA sites and fire treatment distribution (source: Bennett *et al.,* 2014).

those were bulked and sieved and then invertebrates extracted with Tullgren funnels; with invertebrates from each transect then stored in separate vials. These vials were then taken to the laboratory for their analysis, and stored in 70% ethanol. Later they were separated based on the different families using taxonomic keys and microscopes.

After this separation, ants again were analysed individually, with the microscope, taxonomic keys from Shattuck (1998), identifying the different subfamilies and genera. Each of the 75 vials, representing the 75 sampling sites was analysed and the specimens were split into morphospecies. All specimens belonging to the same morphospecies were then redistributed in new vials. This for the case that posterior checking had to be made. They are in the laboratory of bushfire and biodiversity at the Creswick Campus of the University of Melbourne.

Some species have a wide range of colours and different size of workers, called polymorphism, which was also considered at the time of the identification (Greenslade, 1979). Change in colour within a single species can also occur through the effect of the diluted 70% ethanol solution in which the specimens were stored since their collection. The age of the ant may also influence the coloration, making that older specimens are darker than younger ones. Said that, arthropods are not utilized as environmental indicators as often as they could be used. This because to reach the species level identification, specialized taxonomists are required and are rare these days (Oliver and Beattie, 1992). In this study the morphospecies level was reached in the identification, which is the differentiation and classification of individual ants based on variable morphological aspects and does not require an extensive taxonomic training. This method is especially effective for ants and some families of spiders and beetles (Oliver and Beattie, 1996). Morphospecies are also known as RTUs or "recognizable taxonomic unit", first used by Rees (1983).

Ants were identified to the morphospecies level following the protocols of Oliver and Beattie (1996). When more than one species of the same genus was identified based on morphological variance it was labelled with letters and numeric codes, Sp1, Sp2 and so on. This specific identification applies only to this study. Besides that, a specialist in ant morphology was consulted to confirm the previous identification. All identified species are listed in Annex 2 with the subfamily and the functional group they belong. Functional groups are based on the bioclimatic association, competitive interactions and habitat requirements and the identified ants were classified according to the systems of Andersen (1995) and York (2000).

Data Analysis

After the identification ant data was entered in a presence / absence matrix, using the EXCEL software from Microsoft, with abundance values for each site, each treatment and each topographic location, resulting in a matrix from a total of 75 sample sites and with the 31 identified species. With this information the species abundance and richness was determined per sample. Alated (winged) ants and pupae have not been considered in the identification due the complexity of this process. Only workers have been identified in this study.

Treatment effects

The impact of each treatment on the abundance and richness was compared, with data log (ln+1) transformed to get a normal distribution. Effects of fire treatments on response variables (abundance, richness) were tested using Analysis of Variance (ANOVA) in GenStat 16th Edition. A 'factorial plus added control' model was used to test the overall effects of prescribed fire (i.e. control versus all fire treatments irrespective of frequency or season, *burn*), and – by nesting fire frequency by season within *burn* – of fire *frequency* (high versus low), of fire *season* (spring versus autumn), and their interaction. Where significant effects were detected, multiple comparison testing was performed using the Student-Newman-Keuls (SNK) procedure (P=0.05).

Assemblage

This analysis was undertaken with a two-way permutational analysis of variance (PERMANOVA). Area was used as a random factor and treatments as a fixed factor within the area to establish variations of ant communities caused by the treatments. With a pair-wise testing the levels of variance between treatments were tested. Using the similarity percentages (SIMPER), the contribution of each species for the composition of each community across the treatments could be determined. Both analyses were conducted using PRIMER 6 software (Clarke and Gorley, 2006).

Structure (Functional groups)

The identified ants were classified according to the functional group classification of Andersen (1995) and York (2000). The ANOVA test was made with GenStat 16.1 software using the Student-Newman-Keuls test to analyse the impact treatments on the functional group composition.

Habitat

Environmental data was analysed with the IBM SSPS Statistics Ver. 2.2 software to establish which of the 41 measured factors were correlated with ant species richness. Geographic location, elevation, slope and aspect were measured for each sample plot. Dead and live trees were counted recording the basal area and the stem volume. CWD (coarse woody debris) were measured and classified in 5 decay classes, ranking from 1 as less rotten to 5 with highest levels of decomposition. The biomass of leaf litter and properties like moisture content, organic matter content and the carbon nitrogen ratio was also measured and recorded. The elevation was measured but not considered in this analysis because it involves many components of factors like difference in vegetation type, precipitation, soil properties and others.

Then a PCA (principal component analysis) with varimax rotation was used to reduce collinearity of the number of environmental variables. Therefore the program extracts simplified relationships between the factors, to see which factors are related. After that, a Bio-Env procedure generated by PRIMER (v.6.0) software was used for testing the relationship between environmental data and ant assemblage composition across the different FESA sites. For the ant data the Bray-Curtis similarity was used and for the normalised environmental data the Euclidean distance (Clarke and Gorley, 2006). That is how subsets of these abiotic components explaining the biotic pattern of the resulting data were established.

Finally, with the GenStat program an ANOVA test between the variables that had an impact on richness was made to establish if the environmental aspects differed between fire treatments.

RESULTS

Ant diversity:

A total of 3515 ants were identified, belonging to 31 species, 22 genera, five subfamilies and seven functional groups. The richest subfamily was Myrmicinae (12 species), followed by Formicinae with 8 species, then Dolichoderinae with 6 species, Ponerinae with 4 and Myrmeciinae with 1 species respectively. The genus *Anonychomyrma* had 5 species, *Prolasius* had also 5 and *Pheidole* had 3 species. The rest of the genera were represented by a single species. In the control site of Blakeville, 190 specimens of *Paraparatrechina* were collected, which eventually means that a nest of that species was collected. That was the highest number of specimens collected in any of the sample sites, followed by *Anonychomyrma Sp1* with 157 specimens collected in the Burned Bridge spring 3 mid slope sample site.

Rhytidoponera was the most abundant species with 1621 individuals or 46.1 % of all collected ants followed by *Paraparatrechina* with 659 ants or 18.7%, both belonging to the Opportunists functional group (Andersen, 1995 and York, 2000).

Treatment effects:

No significant effect either of abundance (Table 2) or richness (Table 3) of ants related to frequency or season of the prescribed fires or their interactive effects.

In Table 3 the impact of treatments on richness shows very high values for area, which means that a great source of variability is the location of the sample sites, not the fire treatments.

Table 2. ANOVA test for the abundance and the treatments.

Variate: Abundance (ln)					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Area stratum	4	89.25	22.31	1.27	
Area: Treatment					
Burn	1	0.243	0.243	0.14	0.715
Burn . Season	1	1.664	1.664	0.95	0.345
Burn . Frequency	1	0,552	0.552	0.31	0.583
Burn . Seas. Freq	1	0.327	0.327	0.19	0.672
Residual	16	28.093	1.756	1.15	
Area.Treat.Position. Stratum	50	76.081	1.522		
Total	74	115.885			

Table 3. ANOVA test for ant species richness and the treatments.

Variate: Richness					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Area stratum	4	91.547	22.887	5.12	
Area: Treatment					
Burn	1	0.963	0.963	0.22	0.649
Burn . Season	1	0.817	0.817	0.18	0.675
Burn . Frequency	1	0.017	0.017	0	0.952
Burn . Seas. Freq	1	0.017	0.017	0	0.952
Residual	16	71.52	4.47	1.43	
Area.Treat.Position. Stratum	50	156	3.12		
Total	74	320.88			

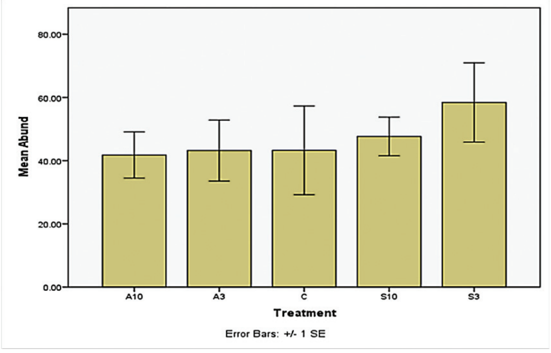

Figure 3. Mean Abundance per treatment.

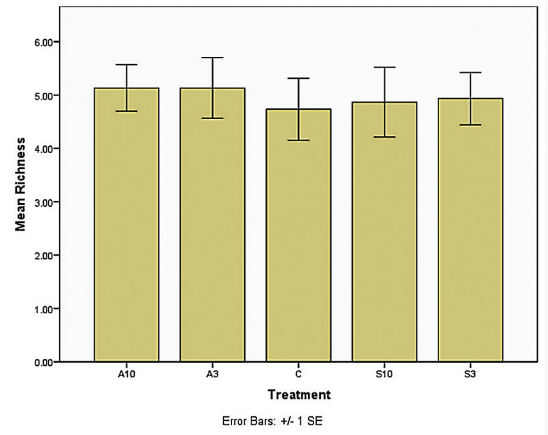

Figure 4. Mean ant species richness per treatment.

Post-hoc testing identified differences in abundance between treatments A10 and S3 (Figure 3); where S3 had the highest number of individuals on average and A10 the lowest. Just the mean values show a trend of lowest abundance values for the autumn fire sites, followed by the control sites and highest abundance values for the sites with fires in spring. Nevertheless the standard errors are so big that there is no statistically significant impact of the different treatments on the ant abundance.

For species richness the highest mean values are for the sites with fires in autumn followed by the ones with fires in spring and with the lowest values for the control sites (Figure 4).

Table 4. Site and treatment effects made with PERMANOVA.

Source	df	SS	MS	**Pseudo-F**	**P(perm)**
Ar	4	27390	6847.5	**4.3457**	**0.001**
Tr(Ar)	20	46868	2343.4	**1.4872**	**0.002**
Res	50	78786	1575.7		
Total	74	1.53E+05			

Again, the standard errors are so big that there is no significant statistical impact.

Assemblage composition:

The PERMANOVA test indicated a significant impact of Area and Treatment (nested with Area) on the ant community composition (Table 4). Using the pair-wise testing the highest level of difference is between treatment A10 and S3 followed by treatments on the Control and S10 sites (Table 5).

Table 5. PERMANOVA test for variance between treatments.

Groups	T	P (perm)
A10, A3	1.0771	0.339
A10, Cont	0.99739	0.425
A10, S10	1.355	0.083
A10, S3	**1.4344**	**0.04**
A3, Cont	1.2627	0.155
A3, S10	1.0266	0.388
A3, S3	1.0641	0.361
Cont, S10	**1.6044**	**0.026**
Cont, S3	1.3214	0.109
S10, S3	1.2418	0.121

The SIMPER analysis showed the contribution of each species on dissimilarity between the treatments, with the 11 species with the largest contribution shown in Table 6, ordered from the highest to the lowest contributor. The SIMPER test revealed that after *Rhytidoponera, Hypoponera* had the second highest level of contribution across the all treatments with the exception of frequent spring fire sites and the control sites, where *Paraparatrechina* had higher levels of contribution. In third place was *Paraparatrechina,* which on the other hand was the second most frequent collected species. *Solenopsis* had very low contributions across all

Opposite column: Table 6. SIMPER analysis of the dominant species and functional groups across the treatments.

		Treatment														
		A10			A3			Control			S10			S3		
	Functional Group	Mean	se	Cont %	Mean	se	Cont %	Mean	se	Cont %	Mean	se	Cont %	Mean	se	Cont %
Rhytidonopera	**O**	14.5	4.2	**46**	18.2	3.2	**64**	13	3.3	**42.8**	28.8	5.6	**72.1**	33.6	7.2	**71**
Hypoponera	**CS**	4.7	2.2	**22**	2.93	1.6	**8.4**	3.67	1.6	**17.4**	3.2	1.1	**13**	3	1.6	**4.9**
Paraparatrechina	**O**	12.9	7.2	**8.9**	12.7	8	**3.4**	13.9	12.6	**48**	0.47	0.4	**0.29**	4	2.8	**5.8**
Anonychomyrma sp. 1	**DD**	1.7	0.7	**7.6**	3.27	1.2	**9**	2.27	1.2	**11.2**	2	0.8	**6.06**	4	10.4	**8.7**
Solenopsis	**CS**	1	0.4	**5.9**	0.8	0.4	**1.7**	0.13	0.1	**0.23**	0.33	0.3	**0**	4	0.1	**0**
Colobostruma	**SP**	1.5	0.8	**3.1**	0.2	0.1	**0.2**	4.67	2.4	**13.8**	0.27	0.2	**0.47**	0.8	0.3	**2.9**
Stigmarcos	**ClSp**	0.5	0.2	**2.1**	1.27	0.7	**5.7**	2.47	1.8	**2.45**	1.27	0.4	**5.04**	0.4	0.3	**0.2**
Anonychomyrma sp. 2	**DD**	1.5	1.1	**1**	0.07	0.1	**0**	0.33	0.3	**0**	1.47	1.3	**0.26**	4	0.1	**0.2**
Prolasius Sp4	**ClSp**	0.4	0.2	**0.8**	0.8	0.6	**0.5**	0.2	0.2	**0**	2.07	1.8	**0.48**	4	0.2	**0.5**
Amblyopone	**CS**	0.1	0.1	**0.4**	0.27	0.1	**1.5**	0.4	0.2	**3.38**	0.13	0.1	**0.12**	0.6	0.2	**4.8**
Prolasius Sp1	**ClSp**	0.2	0.1	**0.2**	0.27	0.2	**0.3**	0.07	0.1	**0**	5.13	4.9	**0.56**	4	0.5	**0.6**

treatments with the exception of the Autumn low frequency sites, which shows that this treatment enhance the presence of this species. The same happened with *Colobostruma,* which had only high values of contribution on the control sites. *Amblyopone* had relatively high contribution values in the control and frequent spring burned sites. Functional groups are also included in this Table and detailed in Table 7.

Assemblage Structure (Functional groups)

Seven functional groups were identified. One of these functional groups was not considered in the statistical analysis, the Subordinate Camponotini, because just 4 individuals of the genus *Polyrhachis* were collected in one of the treatments, which makes them statistically insignificant. *Polyrhachis* was the only genus representing the Subordinate Camponotini.

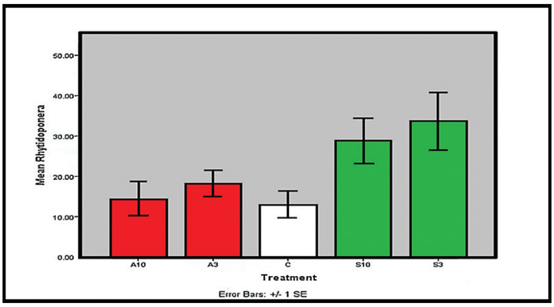

Figure 5. Effect of fire seasonality on the abundance of *Rhytidoponera*.

The ANOVA test revealed no change in functional groups caused by the fire treatments; nevertheless there was a clear shift in species, caused by the seasonality of the fires. *Rhytidoponera* was more frequent in plots with fires lit in spring (Figure 5). *Paraparatrechina* on the other hand was more abundant in plots with fires

Table 7. Identified functional groups (adapted from Gunawardene & Majer 2005 and Andersen *et al.,* 2005).

Functional Group	Genus or subfamily	Description
Dominant Dolichoderinae (DD)	*Iridomyrmex, Papyrus, Anonychomyrma*	Dominate in many of the arid and semi-arid regions of Australia
Subordinate Camponotini (SC)	*Polyrhachis*	Often co-exist with DD due to their submissive behaviour and temporal separation of activity. Characterised by big bodies, mainly active during the night, and arboreal habits
Climate Specialists (ClSp)	*Melophorus, Monomorium, Dolichoderus*	Consist of hot (or cold) climate specialists, which temporally separate their activity by foraging during the hottest or coldest parts of the day or year. Mainly unspecialized.
Cryptic Species (CS)	*Amblyopone, Hypoponera, Discothyrea, Solenopsis, Plagiolepis*	Small species that nest and forage mainly within soil and litter. They often require a complex litter layer.
Generalised Myrmicinae (GM)	*Monomorium, Pheidole, Crematogaster*	At biogeographically scale they can be considered sub dominant after the Dominant Dolichoderinae. Very abundant in warm regions.
Opportunists (O)	*Rhytidoponera, Tetramorium, Paraparatrechina*	Commonly found in disturbed environments as they are poor competitors and are unspecialised in their behaviour. Abundant where behavioural dominance is low.
Specialist Predators (SP)	*Colobostruma, Epopostruma, Orectognathus, Myrmecia.*	Large foragers that prey upon other arthropods

Table 8. Mean and standard error of functional group composition in each treatment.

	S3		S10		Control		A3		A10	
Functional Group	**Mean**	**s.e**	**Mean**	**s.e**	**Mean**	**s.e**	**Mean**	**s.e**	**Mean**	**s.e**
CS	3.867	1.526	4.467	1.640	4.200	1.619	4.067	1.640	5.933	2.157
SP	0.867	0.351	0.400	0.145	4.667	2.419	0.200	0.145	1.667	0.746
GM	0.067	0.067	0.333	0.664	0.200	0.199	0.933	0.664	2.000	1.665
ClSp	1.667	0.653	9.533	1.291	4.600	1.851	3.200	1.291	1.600	0.423
O	37.600	7.204	29.400	8.694	27.000	12.316	30.933	8.694	27.333	7.426
DD	14.067	12.223	3.533	1.433	2.600	1.183	3.867	1.433	3.267	1.482
SC	0.267	0.266	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

in autumn. Nevertheless both species had higher values in burned plots than in the control sites.

In Table 8 the mean and the standard error values for each functional group across each treatment shows again that the Opportunist group had the highest values.

Environmental variables

Of the total of 41 measured environmental variables only 5 were correlated with ant species richness. These variables were leaf litter (< 2mm), soil bulk density (< 2mm), soil carbon/nitrogen ratio (2-5mm), live trees (<100mm in diameter) and CWD decay class 4 (Table 9). The Bio-Env procedure revealed that three environmental variables best explained ant species composition (leaf litter <2mm, soil bulk density <2mm and soil C/N ratio 2-5mm); although the relationship was weak (P = 0.061 (excluding 7 ant species with abundance lower than 3)).

The other 36 variables had no significant effect on the richness or abundance of ants and were therefore not analysed.

An ANOVA test was undertaken to see if these five environmental variables were impacted by the fire treatments and the result was that two of them were. The variables affected by fire were leaf litter less than 2mm and soil bulk density smaller than 2mm (Tables 10 and 11). This reveals that fire treatments have some impact on the measured environmental variables. The strongest impact was on the soil bulk density smaller than 2 mm. This was found especially in between seasonality of fires, and could be related to the organic matter burned, as well as the leaf litter.

Environmental variable	r value	p value
L_LT less than 2mm	0.248	0.032
S_BD smaller than 2mm	0.424	<0.001
S_CN_2-5	0.231	0.046
TLive smaller than 100mm	0.241	0.038
CWD 4	0.257	0.026

Table 9. Environmental variables that impact species richness.

DISCUSSION

Species composition varies across the landscape naturally. That is the reason of the 5 different sample sites of the FESA study, to capture this natural variation. Different canopy cover, proportion of bare ground and density of understorey vegetation are some of the factors influencing ant spatial heterogeneity (Fox,

Table 10. ANOVA results for the leaf litter smaller than 2mm affected by the fire treatments.

Variate: L_LT2mm					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Area stratum	4	33.0477	82.619	6.65	
Area. Treat stratum					
Burn	1	11.2007		9.02	0.008
Burn. Season	1	11.5079	0.963	9.26	0.008
Burn . Frequency	1	5.6311	0.817	0.45	0.510
Burn . Seas. Freq	1	0.709	0.017	0.06	0.814
Residual	16	71.52	4.47	1.59	
Area.Treat.Position. Stratum	50	32.088	320.88		
Total	74	115.344	7.812		

1978; Jackson and Fox, 1996; Greenslade & Greenslade, 1977). Anyways, some species composition change can be attributed to different fire treatments due their effect on the resulting post fire environment (Andersen & Hoffman, 2011; Aponte *et al.,* 2014). Gunawardene and Majer (2005) found no impact of species distribution in burned and long unburned sites, but a significant impact caused by changes in vegetation structure related to fire, comparing three different vegetation types in Western Australia. The complexity of the vegetation structure is an important factor to be considered at the time of analysing the species composition after fire treatments. A non-complex structure seems to recover faster than a highly complex vegetation structure and that impacts the resulting ant species assemblages over time.

As mentioned before, different ant species can be found across sites with different amounts of litter. The clearest examples in this study are *Rhytidoponera*, more abundant on sites with low or no litter (i.e. sites with high fire frequency) and *Paraparatrechina,* more abundant on sites

Table 11. ANOVA results for the leaf soil bulked density smaller than 2 affected by the fire treatments.

Variate: S_BD_0_2					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Area stratum	4	25.796	82.619	7.93	
Area. Treat stratum					
Burn	1	3.823		4.7	0.046
Burn. Season	1	41.328	0.963	5.08	0.039
Burn . Frequency	1	2.468	0.817	3.03	0.101
Burn . Seas. Freq	1	52.872	0.017	6.5	0.021
Residual	16	71.52	4.47	0.7	
Area.Treat.Position. Stratum	50	81.36	320.88		
Total	74	116.344	7.812		

with high litter loads (i.e. in sites with low fire frequency and the unburned sites). Both species belong to the Opportunist functional group. Therefore no change in that functional group was observed, just a shift of species composition caused by the seasonality of the prescribed fires. In a research made by Seymour and Collett (2009) a shift between these two genera was also described.

According to Beaumont *et al.* (2012) *Rhytidoponera metallica* was the most frequent species in their burned and unburned sites with low litter levels. *Rhytidoponera tasmaniensis* was the most frequent species found by Andersen and McKaige (1987) in areas disturbed by humans in Southern Victoria. They mention that this may be attributed to the ecology of this species. It has a very broad and flexible diet, can nest almost everywhere in the soil and feed at a large range of temperatures and light levels. *Rhytidoponera metallica* is known for myrmecochory of *E.obliqua* seeds (Ashton, 1979), one of the dominant tree species in the study area.

If disturbance has a negative effect on other ant species in the same area, this is an advantage of *Rhytidoponera*, who can adapt to the new conditions easily. Ants of this genus are, as many other ant species, scavengers and generalist predators, but they also eat seeds and elaiosomes of myrmecochores (Andersen & McKaige, 1987). Greenslade (1986) mentioned the size of *Rhytidoponera* worker normally bigger than 20 mm compared to the average size of most ant species between 2-5 mm. Compared to other seed dispersing species like *Pheidole* or *Monomorium,* the bigger body size of *Rhytidoponera* is an advantage in myrmecochory in burned areas because they can move faster and have a bigger foraging range in open areas (Parr *et al*., 2007). Majer (1985) also found *Rhytidoponera metallica* as a major seed distributor species in rehabilitated sand mines in Queensland, and as one of the first species appearing after the disturbance. Andersen (1991a) also mentioned the advantages of *Rhytidoponera* over other ant species related to ample range of food sources, flexibility in foraging times and the ability of tolerating a wide range of habitats and spectrum of environmental conditions. Beaumont *et al.* (2011) concluded also that *Rhytidoponera metallica* removes and transports the seeds, while species of *Monomorium* tend to just rob the elaiosome, which also may be related to the size of the ants.

Other advantage over other species is the reproductive cycle of this genus, which is quite particular. Instead of having a single opportunity for reproduction per year as most of the ant species, *Rhytidoponera* can reproduce at any time of the year through mated workers (gamergates) instead of the real queen. That gives this genus a potential of fast colonisation in case of new available habitat created after a disturbance (Haskins & Wheldon, 1965).

In our study this species was the most frequent across the spring treatments, also being abundant in autumn burned plots and control sites. As mentioned before, *Paraparatrechina* had higher abundance in the plots burned in autumn, which can be attributed to the thicker litter layer in these plots. Gunawardene and Majer (2005) also mentioned that Opportunists are very frequent in disturbed areas because they are poor competitors and have unspecialised behaviour. According to the high rates of Opportunists collected in this study we can conclude that these ants are typically the most abundant in this ecosystem type, as there was no significant difference between the functional groups in the burned and the unburned control areas.

After the frequent autumn fire treatments more bare ground might be expected compared to the other treatments because of fewer time to accumulate litter. In response, large ants with bigger bodies and larger legs could be more abundant on sites with this treatment as mentioned by Gosper *et al.* (2015), who found that highly thermophilic functional groups as Dominant Dolichoderinae and Hot Climate Specialists increase their frequency in this type of habitat. On the other hand, in areas with low frequency spring fires, higher levels of litter and a more complex vegetation structure can be expected and therefor functional groups like Cold-Climate Specialists, Cryptic Species and Specialist Predators will be more frequent. Collett (1998) making a comparison between an unburned site and a site that was burned with a frequency of 5 years measured an increase of 23.4% of ants in the burned site, but didn't make a functional group analysis. He also found an increase in arthropod diversity after a second high frequency fire, but not an increase in taxon richness (Collett 2003).

According to the simper test made on the species that contribute the highest levels of variance between the treatments, in frequent spring fires *Rhytidoponera* was the most abundant and *Paraparatrechina* abundance on comparison was very low. *Paraparatrechina* also showed a strong reduction in abundance after an intense fire in heath and mallee vegetation according to Andersen & Yen (1985).

In our study, the soil bulk density probably has an impact on the nests because most ants nest under the ground. There may be a trend about ant species nesting in the range of soils with different bulked density. The carbon/nitrogen ratio (2-5mm) could have an effect on ant species richness related to the abundance of other arthropods and fungi affected by this variable.

Living trees with diameter smaller than 100mm could be related to the vegetation type and canopy cover, which, as discussed above, has a direct impact on ant species richness.

Andersen (1991b) also mentioned that where the impact of fires on ant communities is higher, the higher the rainfall in the area is. That's because ant community composition is based on edaphic and climatic factors and also on vegetation type and structure. The higher the rainfall, the more complex vegetation structure has to be expected and the higher impact of a fire on the structure and floristic composition (Barrow *et al.,* 2007; Andersen *et al.,* 2007). Even if vegetation types in fire prone areas are somehow adapted to certain fire regimes, with the change in these regimes they will suffer a composition change over time (Andersen *et al.* 2005).

In savannas or sclerophyll vegetation, fires have lower impact compared to rainforests or other wet biotas (Parr & Andersen 2008).

Tasker *et al.* (2011) and Beaumont *et al.* (2012) mention that response of ant species composition to fire treatments can differ between vegetation types. Jackson and Fox (1996) described that even 18 years after a fire in dry sclerophyll forests ant community composition was still changing. Ant species succession in forest areas with certain fire frequency has been described recently by Gosper *et al.* (2015). They used a habitat accommodation model, in which species composition is driven by the habitat requirements. The result of their study was that there is a significant variation in functional groups depending on the time since fire, related to the change of habitat (vegetation structure) over the time, and not related to the fire treatment itself. Andersen *et al.* (2014) had similar results with a study they made in the northern territory. They didn't find any difference in species richness or abundance across their treatments, but an increase in both abundance and richness in the plots with high frequency of fires.

Andersen and Yen (1985) described a major change in species composition after a severe fire in heath and mallee vegetation were the abundance of ants was reduced by 50% but the number of species doubled.

York (1999) described a strong reduction in the ordinal diversity of litter dwelling invertebrates in sites burned frequently over the last decades in a sclerophyll forest in New South Wales compared to unburned sites. Fires in long unburned areas have a higher impact in changing the habitat structure, even at low intensity than in higher frequency burned plots (Parr & Andersen, 2008). Andersen (1991b) found a strong impact of different fire regimes on ant species composition and the functional groups in northern Australia.

Normally there is a difference in ant species composition in frequent and unburned sites (Andersen *et al.,* 2005), and similar results have been found in other studies in Australia (York, 2000; Vanderwoude *et al.,* 1997). Hoffmann (2003) found a steady decrease of species richness after time since fire in the Northern Territory. Species richness reached the lowest point after 3 to 5 years after fire and then increased again. Nevertheless the species richness decreases over the time since fire as shown by York (1994).

O'Dowd & Gill (1984) found a increase of *R. victoriae, Stigmarcos sp.* and 2 species of *Prolasius* after high intensity fires in Alpine Ash (*Eucalyptus delegatensis*) forests.

Hoffmann (2003) found that the source of most of the variation of species composition in burned and unburned plots in savanna in the northern territory was due to soil type and the sampling time, not related to fire treatments per se. Other factor to be considered is that different species have different response to different disturbance. As the last fires occurred 3 to 7 years before the sampling, there may have been enough time for the vegetation to restore pre fire conditions. This could be a reason why there was not any impact of the treatments on ant species composition in this study, rather than a stronger impact related to the sampling areas. The vegetation in the FESA study area could also be resilient to the fire treatments and so enhance the resilience of ant species as mentioned by Andersen *et al.* (2005).

CONCLUSION

Fire has shown to have an impact on both vegetation and ant communities. The results presented here demonstrate that the ant assemblages are very resilient to the fire treatments. And even if ants are strongly resilient and no change in the functional groups appeared in this study, more research has to be done to fully understand the impact of changes in frequency and seasonality of the prescribed fires. Furthermore, the cumulative impact of climate change has a direct impact on vegetation structure and habitat. This, in addition to the change of fire regimes, may have a much greater impact on ant community assemblages. If prescribed fire regimes increase in frequency and the vegetation itself is changing, some functional groups may be affected negatively. Nevertheless no significant impact on species assemblages was found in this study. That does not mean that ants are not good indicators for impact assessment of disturbances on ecosystems, rather it shows how complex ecosystems are.

This study has a strong statistical background with 15 replicates of each fire treatment. However, the samplings were made years after the last fire treatments and no significant impact was found across them. The lack of impact may be related to the forest type, which is burned frequently under natural conditions, which could explain why ants from the opportunist functional group are very frequent in disturbed areas or ecosystems with low structural vegetation complexity. Comparing the areas with prescribed fires and the control sites indicated that some increase in richness could be found in the fire areas. These findings are in accordance with the conclusions of other studies. Nevertheless, as mentioned above, this forest type seems to be very resilient to fires, due to environmental variables which were not affected by the fire treatments.

In some areas critical fuel levels can be reached in less than three years, which means that prescribed burnings should be lit with higher frequency in these areas to keep the amount of fuel on low levels. The impact of this new frequency should be analysed as well to measure the potential impact on ecosystemic functionality (York, 2010).

Another recommendation for future studies is that sampling with certain frequency should be made to analyse the change in species composition over time. The sampling should start soon after the fires to measure the fluctuation of species. In this study it was possible thanks to the unburned control sites, but the samples were taken years after the fires, which does not allow for analysis of the change in species composition and abundance after the fires. Greenslade (1973) mentioned that sampling should be repeated on hot and cold days, as well as during the day and the night to have a complete set of species from each plot. Seasonality in sampling can also have an impact on the collected specimens. For example, Neumann (1992) found that ant activities were highest in autumn and summer, showing the impact that seasons can have on the volume of ants collected. The same pattern was found by Abensperg-Traun (1992) who studied ant biomass in 4 different vegetation types and concluded that the highest peaks of activity were during summer and the lowest during winter.

The long-term effect of the prescribed burnings must also be considered. In this study the effect of 30 years of treatments could be analyzed which is important because of the potential change over time in vegetation structure and resulting habitat.

AKNOWLEDGMENTS

First of all I want to express my deep gratitude to Associate Professor Alan York, who with infinite patience went with me through the process of the design and analyzing process of the data. Thanks to him I got a better understanding of ant ecology ant why it is so important to study these insects. Helen Dohtery was very helpful with the species identification and the classification in morphospecies. She showed me that ants can have different colors and even so belong to the same species.

The University of Melbourne, which for me is synonym to academic excellence, gave me a sense for how balanced and efficient research has to be conducted. I also want to thank the Australian Award Scholarship that allowed me to live and study in this beautiful country.

REFERENCES

Abensperg-Traun, M. 1992. Biomass of surface-foraging ants (Formicidae) in four bushland habitats in the wheatbelt of Western Australia. *Journal of the Royal Society of Western Australia.* **75**, 25-32

Andersen, A.N. 1991a. *The ants of Southern Australia: a guide to the Bassian Fauna.* CSIRO. ISBN 0 643 05152

Andersen, A.N. 1991b. Responses of ground-foraging ant communities to three experimental fire regimes in a savanna forest of tropical Australia. *Biotropica*. **23**(4b), 575-585

Andersen, A.N. 1995. A classification of Australian ant communities, based on functional groups which parallel plant life-forms in relation to stress and disturbance. *J. Biogeogr.* **22,** 15-29

Andersen, A.N., Yen, A.L. 1985. Immediate effects of fire on ants in the semi-arid mallee region of north-western Victoria. *Australian Journal of Ecology*. **10**, 25-30

Andersen, A.N., McKaige, M.E. 1987. Ant communities at Rotamah Island, Victoria, with particular reference to disturbance and *Rhytidoponera tasmaniensis*. *Proc.R.Soc. Vict*. **99(**4), 141-146

Andersen, A.N., Penham, T.D., Debas, N., Houadri, M. 2005. Ant community responses to experimental fire and logging in a eucalypt forest of south-eastern Australia. *Forest Ecology and Management.* **258**, 188-197. doi: 10.1016/j.foreco.2009.04.004

Andersen, A.N., Parr, C.L., Lowe, L.M., Müller, W.J. 2007. Contrasting fire-related resilience of ecologically dominant ants in tropical savannas of northern Australia. *Biodiversity and Distributions.* **13**, 438-446

Andersen, A.N., Hoffman, B.D. 2011. Conservation values of low fire frequency in tropical savannas: Ants in monsoonal northern Australia. *Austral Ecology.* **36**, 497-503.

doi:10.1111/j.1442-9993.2010.02151.x

Andersen, A.N., Woinarski, J.C.Z., Parr, C.L. 2012. Savanna burning for biodiversity: Fire management for faunal conservation in Australian tropical savannas. *Austral Ecology*. **37**, 658-667. doi:10.1111/j.1442-9993.2011.02334.x

Andersen, A.N., Ribbons, R.R., Pettit, M., Parr, C.L. 2014. Burning for biodiversity: Highly resilient ant communities respond only to strongly contrasting fires regimes in Australia's seasonal topics. *Journal of Applied Ecology*. **51**, 1406-1413. doi:10.1111/1365-2664.12307

Andrew, N., Rodgerson, L., York, A. 2000. Frequent fuel-reduction burning: the role of logs and associated leaf litter in the conservation of ant biodiversity. *Austral Ecology*. **25**, 99-107.

Aponte, C., Tolhurst, K.G., Bennett, L.T. 2014. Repeated prescribed fires decrease stocks and change attributes of coarse woody debris in a temperate eucalypt forest. *Ecological Applications*. **24**, (5)976-989.

Ashton, D.H. 1979. Seed harvesting by ants in forests of *Eucalyptus regnans* (F.Muell.) in central Victoria. *Australian Journal of Ecology*. **4**, 265-277.

Attiwill, P.M., Adams, M.A .2013. Mega-fires, inquiries and politics in the eucalypt forests of Victoria, south-eastern Australia. *Forest Ecology and Management*, vol. 294, no. The Mega-fire reality, 45-53. doi: 10.1016/j.foreco.2012.09.015

Barrow, L., Parr, C.L., Kohen, J.L. 2007. Habitat type influences fire resilience of ant assemblages in the semi-arid tropics of Northern-Australia. *Journal of Arid Environments*. doi:10.1016/j.jaridenv.2006.08.005

Beaumont, K.P., Mackay, D.A., Whalen, M.A. 2011. Interactions between ants and seeds of two myrmecochorous plant species in recently burnt and long-unburnt forest sites. *Austral Ecology*. **35**, 767-778. doi:10.1111/j.1442/9993.2010.02215.x

Beaumont, K.P., Mackay, D.A., Whalen, M.A. 2012. The effects of prescribed burning on epigaeic ant communities in eucalypt forest of South Australia. *Forest Ecology and Management* **271**, 147-157

Beaumont, K.P., Mackay, D.A., Whalen, M.A. 2013. Multiphase myrmecochory: the roles of different ant species and effects of fire. *Oecologia*. doi: 10.1007/s00442-012-2534-2

Bennett, L.T., Aponte, C., Tolhurst, K.G., Löw, M., Baker, T.G. 2013.Decreases in standing tree-based carbon stocks associated with repeated prescribed fires in a temperate mixed-species eucalypt forest. *Forest Ecology and Management*. **306,**243-255. doi:10.1016/j.foreco.2013.06.036

Bennett, L.T., Aponte, C., Baker, T. 2014. FESA Carbon: effects of repeated planned burns of forest carbon store. DSE/DFES Research Program 2010-2013. The University of Melbourne

Bradstock, R.A., Williams, J.E., Gill, A.M. 2002. *Flammable Australia: The fire regimes and biodiversity of a* continent. Cambridge University Press, Cambridge

Clark, K.L., Skowronski, N., Renninger, H., Scheller, R. 2014. Climate change and fire management in the mid-Atlantic region. *Forest Ecology and Management* **327**, 306-315

Clarke, K.R., Gorley, R.N. 2006. *PRIMER v6: User Manual/Tutorial.* PRIMER-E: Plymouth

Collett, N.G. 1998. Effects of two short rotation prescribed fires in autumn on surface-active arthropods in dry sclerophyll eucalypt forest of west-central Victoria. *Forest Ecology and Management* 107 (1998) 253-273

Collett, N.G. 2003. Short and long term-effects of prescribed fires in autumn and spring on surface active arthropods in dry sclerophyll eucalypt forest of west-central Victoria. *Forest Ecology and Management* **182**, 117-138

Collett, N.G., and Neumann, F. 2003. Effects of repeated low-intensity fire on invertebrates of a mixed eucalypt foothill forest in south-eastern Australia. Research report No.61. *Fire Management Department of Sustainability and Environment*

Del Toro, I., Ribbons, R.R., Pelini, S.L. 2012. The Little things that run the world revisited: a view of ant-mediated ecosystem services and disservices (Hymenoptera: Formicidae). *Myrmecol. News* **17** 133-146. ISSN 1994-4136

Department of Sustainability and Environment. 2003. Ecological impacts of fuel reduction burning in a mixed eucalypt foothill forest – summary report (1984-1999). Fire Research Report No.57, *Department of Sustainability and Environment*, Victoria

Fox, M.D. 1978. Changes in an ant community of coastal heath following sand mining. *Bull. Ecol. Soc. Aust.* **8**

Gosper, C.R., Pettit, M.J., Andersen, A.N., Yates, C.J., Prober. S.M. 2015. Multi-century dynamics of ant communities following fire in Mediterranean-climate woodlands: Are changes congruent with vegetation succession? *Forest Ecology and Management* 342, 30-38. doi:10.1016/j.foreco.2015.01.006

Greenslade, P.J.M., Greensdale, P. 1977. Some effects of vegetation cover and disturbance on a tropical ant fauna. *Insects Soc*. 24, 163-82

Greenslade, P.J.M. 1979. *A guide to the ants of Southern Australia*. South Australian Museum.

Greenslade, P.M.J. in Wallace, H.R.(ed). 1986, *The Ecology of the forests and woodlands of South Australia*, [Adelaide, S. Aust.]: Govt. Printer, 1986.

Gunawardene, N.R., Majer, J.D. 2005. The effect of fire on ant assemblages in the Gibson Desert Nature Reserve, Western Australia. *Journal of Arid Environments.* **63**, 725-739. doi:10.1016/j/jaridenv.2005.04.016

Hasson, A.E.A., Mills, G.A., Timbal, B., Walsh, K. 2009. Assessing the impact of climate change on extreme fire weather events over southeastern Australia. *Climate Research*. **39**, 159-172.

Hastings, C.P., Wheldon, R.M. 1965. 'Queenlessness', worker sibship, and colony versus population structure in the formicid genus *Rhytidoponera. Psyche J. Entomol.* **72**, 87-112.

Hoffmann, B.D. 2003. Responses of ant communities to experimental fire regimes on rangelands in the Victoria River District of the Northern Territory. *Austral Ecology.* **28**, 182-195. doi: 10.1046/j.1442-9993.2003.01267.x

Höllerdobler, B., Wilson, E.O. 1990. *The ants*. Cambridge, Mass.: Belknap Press of Harvard University Press

Jackson, G.P., Fox, B.J. 1996. Comparison of regeneration following burning, clearing or mineral sand mining at Tomago, NSW: II. Succession of ant assemblages in a coastal forest. *Australian Journal of Ecology* 21, 200-216. doi: 10.1111/j.1442-9993.1996.tb00600.x

Krebs, P., Pezzatti, G.B., Mazzoleni, S., Talbot, L.M., Condera, M. 2010. Fire regime: history and definition of a key concept in disturbance ecology. *Theory in Biosciences* 2010, Volume 129, Issue 1, pp 53-69. Springer Verlag

Luke, R.H., McArthur, A.G. 1978. *Bushfires in Australia*. Australian Government Printing Service, Canberra, ACT, 359 pp.

Majer, J.D .1985. Recolonization by ants of rehabilitated mineral sand mines on North Stradbroke Island, Queensland, with particular reference to seed removal. *Australian Journal of Ecology.* **10**, 31-48. doi: 10.1111/j.1442-9993.1985.tb00861.x

Manwaring, M., Eliot, M., Barton, P., Weaver,

H. 2014. Effects of fire on vegetation and arthropods in a coastal heath, south-east Queensland. *Ecological Management & Restoration*. Vol. 16. doi:10.1111/emr.12136

Neumann, F.G. 1992. Responses of foraging ant populations on high-intensity wildfire, salvage logging and natural regeneration processes in *Eucalyptus regnans* regrowth forest of the Victorian Central Highlands. *Aust. For.***55**, 29-38

O'Dowd, D.J., Gill, A.M. 1984. Predator satiation and site alteration following fire: mass reproduction of Alpine Ash (*Eucalyptus delegatensis*) in southeastern Australia. *Ecology*. **65** (4) 1052-1066

Oliver, I., Beattie, A.J. 1992. A Possible method for the rapid assessment of biodiversity. *Conservation Biology* Vol.7, No. 3 p.562.

Oliver, I., Beattie, A.J. 1996. Invertebrate Morphospecies as surrogates for species: A case study. *Conservation Biology* Vol.10, No. 1 99-109

Parr, C.L., Andersen, A.N., Chastagnol, C. 2007. Savanna fires increase rates and distance of seed dispersal by ants. *Oecologia*. **151**, 33-41. doi:10.1007/s00442-006-0570-5

Parr, C.L., Andersen, A.N. 2008. Fire resilience of ant assemblages in long-unburned savanna of Northern Australia. *Austral Ecology*. **33**, 830-838. doi:10.1111/j.1442.9993.2008.01848x

Rees, C.J.C. 1983. Microclimate and the flying Hemiptera fauna of a primary lowland rainforest in Sulawesi. *Tropical Rainforest: Ecology and management*. Blackwell Scientific Publications. Oxford England. 121-136

Shattuck. S.O. 1998. ***Australian ants****: their biology and identification*. Collingwood, Vic. : CSIRO, 1998.

Seymour, B. Collett, N.G. 2009. Effects of fire retardant application on heathland surface-dwelling ant species (Order Hymenoptera; Family Formicidae) in Victoria, Australia. *Forest Ecology and Management*. **257**, 1261-1270. doi:10.1016/j.foreco.2008.11.025

Shrestha, H.R., Weston, C., Baker, T. 2012. Effects of repeated planned burning on Carbon fractions in Forest soils. *Bushfire CRC*. University of Melbourne

Tasker, E.M., Denham, A.J., Taylor, J.E., Strevens, T.C. 2011. Post-fire seed predation: Does distance to unburnt vegetation matter? *Austral Ecology*. **36**, 755-766. doi:10.1111/j.1442-9993.2010.02214x

Tolhurst, K. & Flinn, 1992. Ecological impacts of fuel reduction burning in dry sclerophyll forest. Research report (Victoria. Forest Research Centre); no.349

Underwood, E. C., Fisher, B.L. 2006. The role of ants in conservation monitoring: If, when, and how. *Biological Conservation*, vol. 132, pp. 166-182. doi: 10.1016/j.biocon.2006.03.022.

Vanderwoude, C., Andersen, A.N., House, A.P.N., 1997. Ant communities as bioindicators in relation to fire management of spotted gum (*Eucalyptus maculata* Hook.) in forests in south-east Queensland. *Memories Museum Victoria.* **56**, 671-675

York, A. 1994. The long term effects of fire on forest ant communities: Management implications for the conservation of biodiversity. *Memories of the Queensland Museum.* **36**, 231-239

York, A. 1999. Long-term effects of frequent low-intensity burning on the abundance of litter dwelling invertebrates in coastal blackbutt forests in southeastern Australia. *Journal of Insect Conservation* **3**, 191-199

York, A. 2000. Long-term effects of frequent low-intensity burning on ant communities in coastal blackbutt forests in southeastern Australia. *Austral Ecology* **25**, 83-98

York, A., Bell, T.L., Weston, C. 2012. Fire regimes and soil-based ecological processes: implications for biodiversity. Pp. 127-148 in R.A. Bradstock, R.J. Williams & A.M. Gill (Eds.) *Flammable Australia: Fire Regimes, Biodiversity and Ecosystems in a Changing World.* CSIRO Publishing, Collingwood, Victoria. ISBN 9780643104822

York, A. 2012. Protocol: Leaf litter sampling for terrestrial invertebrate sampling Wombat FESA

York, A. 2014. Changing fire regimes: The response of litter-dwelling invertebrates to altered seasonality and frequency of fire. Pp. 519-526 in D.X. Viegas (Ed.) *Advances in Forest Fire Research.* University of Coimbra, Portugal. http://dx.doi.org/10.14195/978-989-26-0884-6

Annex 1: Leaf litter sampling protocol

Protocol: Leaf litter sampling for terrestrial invertebrate sampling

Wombat FESA

Prepared by: Alan York (13th February 2012)

Collections will be undertaken along the 2 x 18m CWD (Coarse Woody Debris) transects at each of the 75 plots (5 locations x 5 burn treatments x 3 plots (ridge, slope & gully)).

At 10 systematically located points along each of the 2 transects (20 points), 2000cm^3 of surface litter will be collected (constant volume sampling*). A total of 0.04 m^3 of litter will be collected from each plot**.

There will be some stratification as part of the sampling process to make sure that at the following micro-habitats are sampled (adjacent to CWD, adjacent to a tree, in the open). Numbers of each of these samples will approximately reflect the relative frequency of these micro-habitats (in open > adjacent tree > adjacent CWD).

Each sample point will be marked with a fluoro-painted bamboo skewer inserted in the soil to avoid interference with subsequent soil and litter measurements (Carbon sub-project).

Disturbance will be kept to a minimum*** (no soil disturbance), although some litter disturbance will occur in the immediate vicinity of the star picket where litter from the sieving process is discarded.

---

* For simplicity we use a 2 litre (2000cm^3) ice-cream container as a sampling 'tool'. Litter is collected by hand, down to mineral earth but not including humus incorporated into the soil. Enough litter is collected at each point to fill the 2 litre container (slightly compacted).

** Litter samples are bulked and then processed (concentrated) on site using a hand-held sieving device. A single sample is then taken to the laboratory for invertebrate extraction.

*** The disturbance footprint will depend on litter depth. We use a volumetric approach because it is hard to define an 'area' adjacent to CWD and trees where litter is often deeper and more decayed. Generally we are talking about an area approximately 30cm x 30cm. With 20 samples per plot this is miniscule compared with the total area of the plot.

Annex 2: Identified morphospecies

Morphospecies	Subfamily	Functional group
Rhytidoponera	Rhytidoponera	Opportunists
Paraparatrechina	Formicinae	Opportunists
Tetramorium	Myrmicinae	Opportunists
Pheidole sp. 1	Myrmicinae	Generalised Myrmicinae
Pheidole sp. 2	Myrmicinae	Generalised Myrmicinae
Pheidole sp. 3	Myrmicinae	Generalised Myrmicinae
Monomorium	Myrmicinae	Generalised Myrmicinae
Anonychomyrma sp. 1	Dolichoderinae	Dominant Dolichoderinae
Anonychomyrma sp. 2	Dolichoderinae	Dominant Dolichoderinae
Anonychomyrma sp. 3	Dolichoderinae	Dominant Dolichoderinae
Anonychomyrma sp. 4	Dolichoderinae	Dominant Dolichoderinae
Anonychomyrma sp. 5	Dolichoderinae	Dominant Dolichoderinae
Stigmarcos	Formicinae	Climate Specialist
Strumigenys	Myrmicinae	Climate Specialist
Dolichoderus	Dolichoderinae	Climate Specialist
Mayriella	Myrmicinae	Climate Specialist
Prolasius sp. 1	Formicinae	Climate Specialist
Prolasius sp. 2	Formicinae	Climate Specialist
Prolasius sp. 3	Formicinae	Climate Specialist
Prolasius sp. 4	Formicinae	Climate Specialist
Podomyrma	Myrmicinae	Climate Specialist
Amblyopone	Ponerinae	Cryptic Species
Hypoponera	Ponerinae	Cryptic Species
Dicothyrea	Ponerinae	Cryptic Species
Solenopsis	Myrmicinae	Cryptic Species
Plagiolepis	Formicinae	Cryptic Species
Colobostruma	Myrmicinae	Specialist Predator
Orectognathus	Myrmicinae	Specialist Predator
Myrmecia	Myrmeciinae	Specialist Predator
Epopostruma	Myrmicinae	Specialist Predator
Polyrhachis	Formicinae	Subordinate Camponotini