Effects of fire history on ground dwelling arthropods abundance, species richness, diversity and composition in a semi-arid woodland savanna, Waterberg Plateau Park, central Namibia

Mini-thesis presented in partial fulfilment of the requirements for the degree of Bachelor of Natural Resources Management (Honours) at

Namibia University of Science and Technology.

BY

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Declaration

I, Nekulilo Uunona hereby declare that the work contained in the mini-thesis, entitled Effects of fire history on ground dwelling arthropods abundance, species richness, diversity and composition in an arid woodland savanna, Waterberg Plateau Park, central Namibia, is my own original work and that I have not previously in its entirety or in part submitted it at any university or other higher education institution for the award of the degree.

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I, Nekulilo Uunona, being a candidate for the degree of Bachelor of Natural Resources Management (Honours) accept the requirements of the Namibia University of Science and Technology relating to the retention and use of mini-thesis deposited in the Library.

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ABSTRACT

The lack of knowledge on arthropods and fire is an important shortcoming to understanding how savanna systems are structured and function. We know little about the effects of fire history on arthropods especially in Namibian woodland savannas, despite the fact that fire has been used there as a management tool for many years.

This study compared the effects of time since last burn on ground dwelling arthropod's abundance, species diversity, and composition in the Waterberg Plateau Park, Central Namibia. The study was done in 4 fire treatments with different fire histories. 1: burned 3 years ago, treatment 2, 3 and 4 burned 4, 16 and 26 respectively. Six existing randomly selected line transects (200 m) were surveyed in each of the fire zones. Data were collected at 40 m intervals along each transect. Each transect had five pitfall traps and each fire block had 30 pitfall traps. Pitfall traps were emptied and collected after 3 days. The study lumped each of 5 traps of each transect into one sample) (N = 6). One-way ANOVA was used to test for significant differences in abundance, and diversity (Shannon diversity index and species richness) among the different fire blocks. The survey collected 1,755 individuals which represented 99 morpho species and 13 taxonomic orders. Of this total, 96% were insecta, 3% arachnids, 1% Myriapod. The study found inconsistent differences unrelated to time since last burn. There was a statistical significant difference in abundance between the treatments and no statistical significant difference in diversity. NMS revealed that litter, grass density and woody cover were the driving variables for community composition, with litter being the strong variable towards treatments burned 16&26 years. The findings of this study mean that time since last burn has little effects on ground dwelling arthropods abundance and species richness and inconsistent effects on Shannon diversity. Other variables other than fire (secondary effects such as litter, grass density and woody cover) seem to be driving the effects.

Keywords: *Similarities; Shannon; Fire regime; Litter; Ecosystem services*

1. INTRODUCTION

1.1. ECOLOGICAL IMPORTANCE / ECOSYSTEM SERVICES PROVIDED BY ARTHROPODS

The name “arthropod” comes from two Greek words, *arthros,* “jointed,” and *podes,* “feet” meaning that all arthropods have jointed legs (Picker, Griffiths, & Weaving, 2002). The phylum Arthropoda includes insecta, arachnids, mryapods, and crustaceans (Picker *et al*, 2002). Arthropods are the most diverse and successful life forms on earth, because they make up over 80% of the total biomass of land animals (Cranshaw & Redak, 2013). Insects alone, with approximately 970,000 known species, make up over one-half of all kinds of life known to occur on the planet (Cranshaw & Redak, 2013). “Known species,” are those that have been described in the scientific literature and accepted as distinct species (Cranshaw & Redak, 2013). There are about 6000000 species or more that have been undescribed (Picker *et al*, 2002).

Arthropods are important components of terrestrial systems, contributing significantly to biodiversity and ecosystem structure and function (Picker *et al*, 2002). Ground dwelling arthropods are important in our lives and for the functioning of our ecosystems. A number of ecosystem services provided by different feeding guilds of arthropods are as follows: springtails and mites contribute to decomposition and nutrient cycling (Vlug & Borden, 1973; Metz & Dindal, 1975). Ants change minerals and organic composition of soils, which helps drainage and infiltration rates and some disperse seeds (Davies, Rensburg, & Berndt, 2010). Many insects grow by feeding on dead plant and animal matter or animal dung e.g. dung beetles (Cranshaw & Redak, 2013). These insects function as macro decomposers, which is of important to the recovery and recycling of nutrients that are held-up in these organic matters (Cranshaw & Redak, 2013). Through this, these substances are broken down into much smaller particles which to a greater degree speeds up the process of decomposition that releases the nutrients for plant growth (Cranshaw & Redak, 2013). Additionally, most of terrestrial arthropods such as ants, termites, beetles live in the soil for shelter and as a substrate for eggs and other inactive life stages (Higgins, Cobb, Sommer, Delph, & Brantley,2014), these animals help in soil formation by moving and mixing huge amounts of soil as they tunnel which is important for soil infiltration (Cranshaw & Redak, 2013).

Some arthropods are pollinators, e.g. bees and wasps (Buse & Good, 1993). Arthropods also act as predators and prey in food chains (Peterson & Luxton, 1982; Buse & Good, 1993;

Gunnarsson, 1996, Kevan, 1999; Chamberlain *et al.*, 2006). These processes are not only vital to soil formation but also to the maintenance of soil fertility. (Cranshaw & Redak, 2013).

1.2. FIRE IN SAVANNA ECOSYSTEMS

Savannas represent one of the major biomes of the southern hemisphere and occupying about 20% of the land surface of the Earth and 40% of Africa's land surface (Scholes & Hall, 1996). Savannas are important because they are the foundation of industries like cattle ranching, wildlife and biodiversity conservation (van Wilgen, 2009). Their distribution and structure is determined mostly by factors such as fire, water availability, soil type, nutrient availability and herbivory (van Wilgen, 2009). Particularly, fire has been recognized as an integral part of African savanna ecosystems since the Miocene, which is a period extending from about 5 to 23 million years ago (Osborne, 2008) and has been reported to have acted not only destructively but also as an ecosystem regulatory agent (Goldammer, 1990; Scholes & Walker, 1993; van Wilgen, 2009).

Savannas have a long dry season, which together with abundant grass fuels make them highly flammable (Scholes & Hall, 1996) to both naturally ignited and anthropogenically applied fires (van Wilgen, 2009). In savanna systems fire is a key determinant of species composition and structure in both fauna and flora communities (Davies *et al.*, 2010). Fire helps in maintaining open systems and by maintaining woody species at a browsable level (Joubert, Rothauge & Smit, 2008), whereas in the fauna community e.g. arthropods, not much is known about their reaction to fire and previous studies have often reported the indirect effects such as their relationships with the altered vegetation, removal of litter and increased soil temperature (Anderson *et al.*, 1989; Willig & McGinley, 1999). Although fire is a vital ecosystem process in savannas, there is lack of understanding on the response of biodiversity to fire and not much has been documented.

1.3. EFFECTS OF FIRE ON ARTHROPODS IN ECOSYSTEMS

Arthropods can be useful effective indicators of environmental changes because they are sensitive to disturbances such as fire, and change in soil composition and structure (Higgins *et al.*, 2014).

Fire effects have been studied in fire-prone ecosystems worldwide, with much focus on vegetation but less effort has been made to understand the response of arthropods to fire (Davies *et al.*, 2010), and thus the response of arthropods (particularly ground-dwelling) to fire remains unclear (Colby, 1990; Hanula & wade, 2002).

Fire may directly affect ground dwelling arthropods by increasing soil temperature and exposure during combustion because the soil provides shelter for the invertebrates as well as a substrate for eggs and other inactivity life stages (Higgins *et al.*, 2014). Additionally, fires can directly cause mortality on immobile stages or indirectly affect them via changes in habitat availability and quality (Mitchell, 1990; Swengel, 2001). The lack of knowledge on invertebrates and fire is thus an important shortcoming to understanding how savanna systems are structured and function (Davies *et al.*, 2010), especially as savannas often experience intense fires (van Wilgen, Govender, & Biggs, 2007).

1.4. SHORT TERM EFFECTS OF FIRE ON ARTHROPODS IN ECOSYSTEMS

A review by Swengel (2001) on insects' responses to fire highlights that many insects decline drastically during and after fire (0-2 months), depending on the degree of exposure to flames and their stage of development. However, arthropods living in the soil are unlikely to be affected by fire and many ground dwelling arthropods may escape flames by hiding for a short time in soil cracks and under rocks (Warren, Scifres, & Teel, 1987). Their rate of increase after fire depends on their ability to gain access to the re growing vegetation (Swengel, 2001).

Uys *et al* (2006) looked at the short term (2 and 12 weeks after fire) response of grassland invertebrates to fire on the Drakensberg in South Africa and found that the distance from burn edge negatively affected invertebrate richness and abundance, especially for flying insects. Their study found that burning had no impact on wingless invertebrates, suggesting that they tolerate fire by finding refuges. A study by Hanula (2003) in the pine flatwoods ecosystem found low diversity of arthropods on annually burned plots compared to biennially and quadrennial plots which is said to be due to insufficient time in recovering for the plots burned annually and so the extent to which fire burns is important.

1.5. LONG TERM EFFECTS OF FIRE ON ARTHROPODS IN ECOSYSTEMS

Long term effects of fire on arthropods vary. After fire, some taxa continue to exist in lower numbers, some become similar to controls, and some, especially grasshoppers (Orthoptera) and ground beetles (Coleoptera: Carabidae), become more abundant (Swengel, 2001). In addition some studies recorded a significant decline of herbivorous beetle richness (1 year after fire), while carnivorous beetle richness remained unchanged.

Parr *et al* (2004) on the response of African savanna ants to long-term fire regimes in the Kruger National Park found no significant effect of different fire regimes on mean ant species richness and abundance between treatments. The study was a 50 year fire experiment on 4 savanna vegetation types, namely Mopane woodland, *Acacia* savanna and *Terminalia* woodland) in Kruger National Park, South Africa. Their plots burned in August and April annually, biennially and triennially. In Southern Australian savannas, Anderson & Muller (2000) reported that fire has little long-term effects on the abundance of arthropods and nothing was mentioned on the effects of fire on species richness and composition.

Given the prevalence of fire in these systems and the gaps in our understanding, this study is important and will aid in making ecologically informed fire management decisions for effective biodiversity conservation. This study will use a space-for-time substitution approach to analyse temporal trends (Pickett, 1989) from a series of fire blocks of different times since last burn. This study is investigating the effects of fire history (time since last burn) on ground dwelling arthropods abundance, species richness and diversity in a semi-arid woodland savannah. It is part of a bigger study looking at the impacts of fire on biodiversity and ecosystems in an arid woodland savanna, Waterberg Plateau Park under the Southern African Science Service Centre for Climate change and Adaptive Land management (SASSCAL).

2. PROBLEM STATEMENT

The response of ground dwelling arthropods to fire is one of the understudied topic in most ecosystems worldwide (Pryke & Samways, 2012). A critical gap in our understanding remains, in that we know little about impacts of fire on ground dwelling arthropods especially in Namibian woodland savannas, despite the fact that fire has been used there as a management tool, ranging from semi exclusion of fire to annual burning for many years.

KEY RESEARCH OBJECTIVES, QUESTIONS AND HYPOTHESES

The overall aim of the study is to investigate the effects of fire history on ground dwelling arthropod's abundance, species richness and diversity in the Waterberg Plateau Park, Central Namibia. There is a current study looking at bees and wasps on the Waterberg, so this study will only focus on ground dwelling arthropods since they are the most diverse compared to other arthropods.

The specific objectives of the study are to compare the effects of time since last burn on the Waterberg Plateau on the following:

(a) Ground dwelling arthropod diversity
(b) Ground dwelling arthropod abundance
(c) Community composition

The study will seek to answer the following questions:

(a) How the current fire regimes affect ground dwelling arthropods alpha and beta diversity?
(b) How the current fire regimes affect ground dwelling arthropod abundance?
(c) How the current fire regimes affect community composition?

Null Hypothesis: Current fire regimes will not affect arthropod diversity, abundance, and community composition.

The research hypothesis of the study is:

Current fire regimes will affect arthropod diversity, abundance, and community composition

3. STUDY SITES AND METHODS

3.1.1. STUDY AREA

The Waterberg Plateau Park (WPP) is found in central Namibia, about 280 km northeast of Windhoek and about 60 km east of Otjiwarongo (Figure 1).The park is about 47 000 ha in extent, of which 46 500 ha is on the plateau. The study site is located on the northern part on the Plateau. Waterberg Plateau Park is found in a more arid end of the Savanna and Kalahari Woodland vegetation type of Namibia (Giess, 1971). The vegetation at the study site and area is dominated by *Terminalia sericea*, *Burkea africana, Ochna pulchra*, *Combretum collinum, Combretum psidioides*, *Acacia ataxacantha*, *Acacia fleckii, Grewia flavescence* and *Bauhinia petersiana* (Schneider, 1993). Grass species includes *Eragrostis pallens*, *Eragrostis jeffreysii*, *Brachiaria nigropedata*, *Digitaria seriata,* and *Panicum kalaharense* (Schneider, 1993).

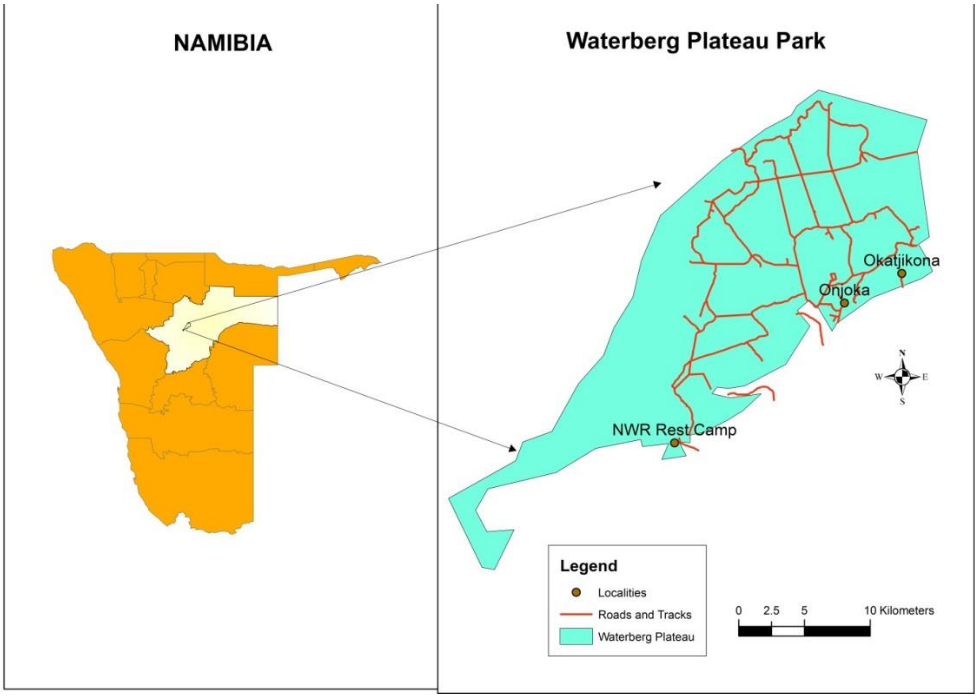


Figure 1 Location of Waterberg in Namibia (source: Amputu 2016)

The park was proclaimed in 1972, originally as a sanctuary for rare and endangered species including Buffalo (*Syncerus caffer)*, Eland (*Taurotragus oryx*), Giraffe (*Giraffa camelopardalis)*, Kudu (*Tragelaphus strepsiceros*), Red hartebeest (*Alcelaphus buselaphus)*, Klipspringer (*Oreotragus oreotragus*), Duiker (*Sylvicapra grimmia*), Steenbok (*Rhaphicerus campestris*), Warthog (*Phacochoerus africanus*), Sable antelope (*Hippotragus niger*), and Roan antelope (*Hippotragus equinus*)(Schneider, 1993). The park is free of large predators, apart from Cheetah (*Acinonyx jubatus*), Leopard (*Panthera pardus*), Brown hyena (*Hyaena brunnea*), and Caracal (*Felis caracal*) (Eco Impacts Consultants 2011; Mukaru, 2009).

The park is estimated to have about 200 bird species including birds of prey such as, Cape vulture, Lapped face vulture, White backed vulture, Tawny eagle, Black eagle and Pale chanting goshawk. Smaller near endemic birds include Hartlaub’s spurfowl, Monteiro’s hornbill, Damara hornbill, Carps tit and Herero chat.

PHYSICAL FEATURES, GEOLOGY AND SOILS OF THE STUDY SITE

The Sandstone plateau rises up to 200 m above the surrounding plain and is on average between 1550 m and 1850 m above sea level (Mukaru, 2009). It extends about 50 km in length and 16 km in width (Eco Impact Consultants, 2011). **.** The top of the plateau is made up of solidified dunes, known as aeolianite, which belongs to the Etjo formation and forms part of the Karoo sequence (Mukaru, 2009). The sandstone is covered by Kalahari sand from the

Kalahari Basin and is brownish to light grey and medium grained (Erb, 1993). The soil is sandy with relatively low clay content (approximately 3 - 4%) with pH ranging from 3.6 to 6.0 (Erb, 1993; Erckie, 2007, Nghalipo, 2016). In addition, the soil is very nutrient-poor as it was derived from red quartzite sand, which is heavily leached (Mukaru, 2009).

3.1.2. CLIMATE

The total rainfall amount for the rainfall seasons from years 2012 – 2015(3 seasons) as recorded by the SASSCAL weather station on the plateau was 279.10 mm, 811.39 mm, and 296.19 mm respectively. The average minimum temperatures recorded by the SASSCAL weather station on the plateau for the cold period (May to September) for the years 2012, 2013, 2014 and 2015 were -4.2 ^{0}C, -3.6 ^{0}C, -2.1 ^{0}C and -9.1 ^{0}C respectively, while the average maximum temperatures for years 2012, 2013, 2014 and 2015 were 31.5 ^{0}C, 32.7 ^{0}C, 30.4 ^{0}C and 36.5 ^{0}C respectively.

3.2. METHODS

The study was done in 4 fire treatments (Fig 2.) with different fire histories (table 1.) Treatment 1: burned 3 seasons ago, treatment 2, 3 and 4 burned 4, 16 and 26 respectively.

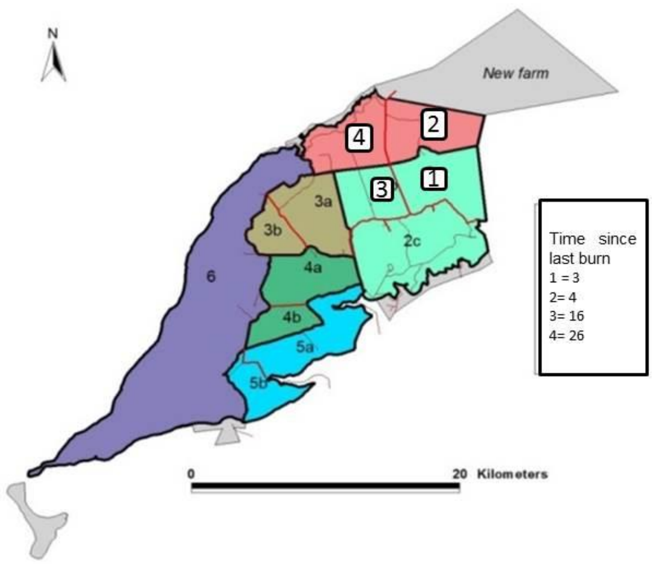


Figure 2: location of study sites on the Waterberg (Source: Eco Impacts Consultants, 2011).

Table 1: the different fire zones with their fire interval and TSLB (from Joubert, 2003: unpublished data)

Treatment	Mean fire return interval (years)	Time since last burn (years)
1	6.2	3
2	9.3	4
3	9.3	16
4	18.5	26

This survey used pitfall traps to trap ground dwelling arthropods, one of the few standardized methods for trapping ground dwelling arthropods (Work, Buddle, Korinus, & Spence, 2002). All trapped invertebrates were collected and recorded. Six existing line transects (200 m) randomly selected for previous studies in 2014-2015 were surveyed in each of the fire zones during March to April 2016. Transects were 1 km away from waterholes to minimize waterhole effects. Data were collected at 40 m intervals along each transect. Each transect had five pitfall traps (each fire block had 30 pitfall traps). A pitfall trap (500 ml clear plastic cup) was placed into the soil that was dug with a shovel and covered at ground level (rim must be flush with the soil, figure 3). The cup had saturated salt water to prevent insects from escaping and preserving them afterwards before collection. Pitfall traps were labelled according to their locations. E.g. point and zone of transect to know where each was collected. Pitfall traps were collected and emptied after 3 days including both nocturnal and diurnal species.

Figure 3: Pitfall trap set up

The study "lumped" each of 5 cups of one transect as one sample (n=6). All species trapped were collected, placed in vials according to the locations they were captured from, preserved in 70% Ethanol and taken to Namibian University of Science and Technology (NUST) for storage and further identification. The trapped ground dwelling arthropods were identified to morpho-species level. A morpho species is species defined by its appearance (Work et al, 2002).

3.3. DATA ANALYSIS

(a) Ground dwelling arthropod diversity

The Shannon index formula (H') (Magurran, 2013), was calculated for each fire treatment and comparisons were made.

Formula: $H' = - \sum p_i ln\, p_i$

p_i = the proportion of a species

ln = natural logarithm

Other indices, such as Simpson's index and Berger- Parker index were explored (Magurran, 2013).

One way ANOVA was used to test for significant differences in diversity indices (H'), and abundance among the different fire treatments (1, 2, 3, 4,). Due to the inconsistency of the results across different orders of arthropods, the study dwelled into the dominant families: Formicidae, Tenebrionidae, Scarabidae, Carabidae and one order Orthoptera and further statistically analysed them using One way Anova to test for significant differences in species richness and abundance among the different treatments.

(b) Species composition

The different treatments were compared by performing a non-metric multidimensional scaling (NMS) ordination in PC-ORD 6 (McCune & Mefford, 2011). Ordination is defined by McCune & Grace (2002) as "a method of graphically summarising complex relationships, extracting one or few dominant patterns from infinite possible patterns". In community ecology ordination is used mainly to describe the strongest patterns in species composition. This is done based on the fact that species abundance differs along environmental or historical gradients (McCune & Grace, 2002). Therefore, ordination orders sampled units along gradients.

The NMS was run on data for different morpho species among the treatments. The environmental variables used in the ordination were: litter, woody cover and grass density provided by Amputu (2016). Sorenson distance measure was used with a random seed supplied by the user. From the scores of the ordination, joint plots were used to show the findings. Joint plots show the relationship between a set of environmental variables and ordination scores as a diagram with radiating lines (McCune & Grace, 2002).

4. RESULTS

A total of 3,381 individuals were collected and sorted. Of this total, 1627 were a dominant ant species which has been excluded for analysis and only considered for species richness. So with the exclusion of the dominant ant species, 1755 species were used for this study. Of 1755 species, 96% were Insecta, 3% Arachnids and 1% Myriapoda and they represented 13 taxonomic orders.

The most abundant Order was Hymenoptera 62.6%(of which 97% are ants) followed by Coleoptera 25.5%,(of which 60% was a common Tenebrionidae species) Orthoptera 3.1%, Blattodea 2.3%, Araneae 1.9%, Diptera 1.1%, Centipede 0.8%, Solifugae 0.6%, Hemiptera 0.6%, Lepidoptera 0.5%, Scorpions 0.4%, Mantodea 0.2%, and Isoptera 0.1% respectively (Figure 4 &5).

The survey collected 99 morpho species (Including the dominant social ant). The orders with most morpho species were Coleoptera, Hymenoptera and Orthoptera . Morpho species of order Isoptera occurred only in treatment 1 and Mantids occurred only in treatment 1 and 3 and the rest occurred among all treatments. Ground dwelling arthropods species richness declined with increasing in time since last burn (Table 2).

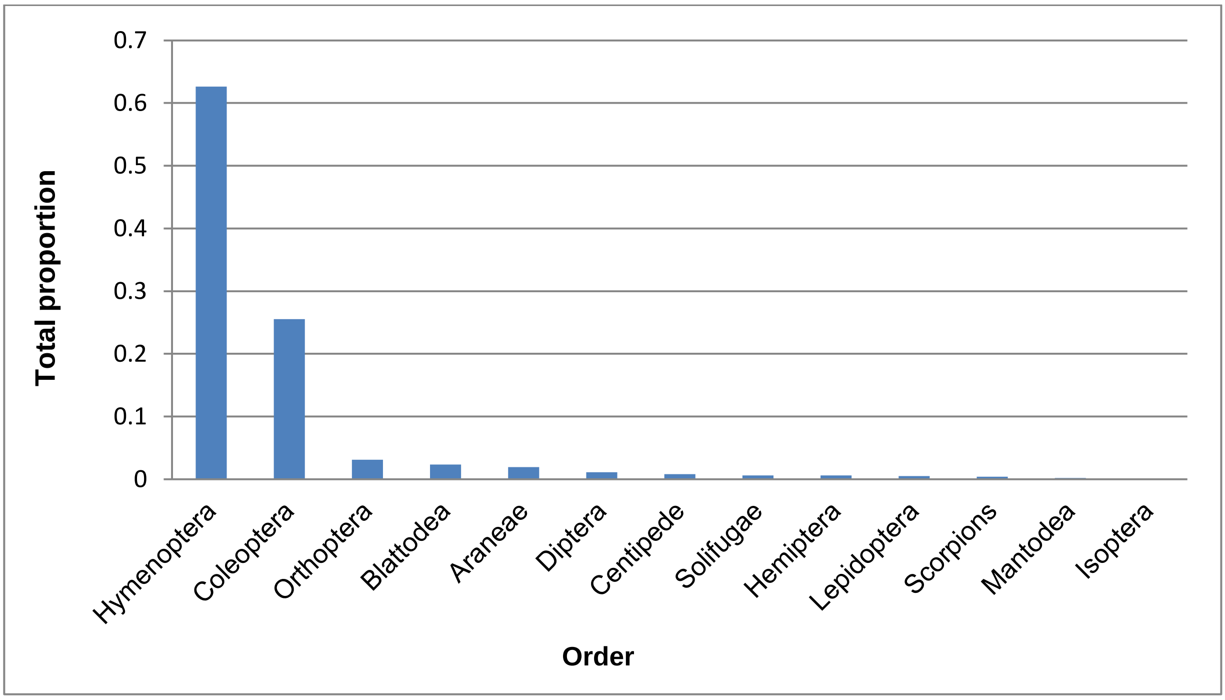


Figure 4: Proportional abundance of arthropod orders obtained from four fire treatments with different fire histories.

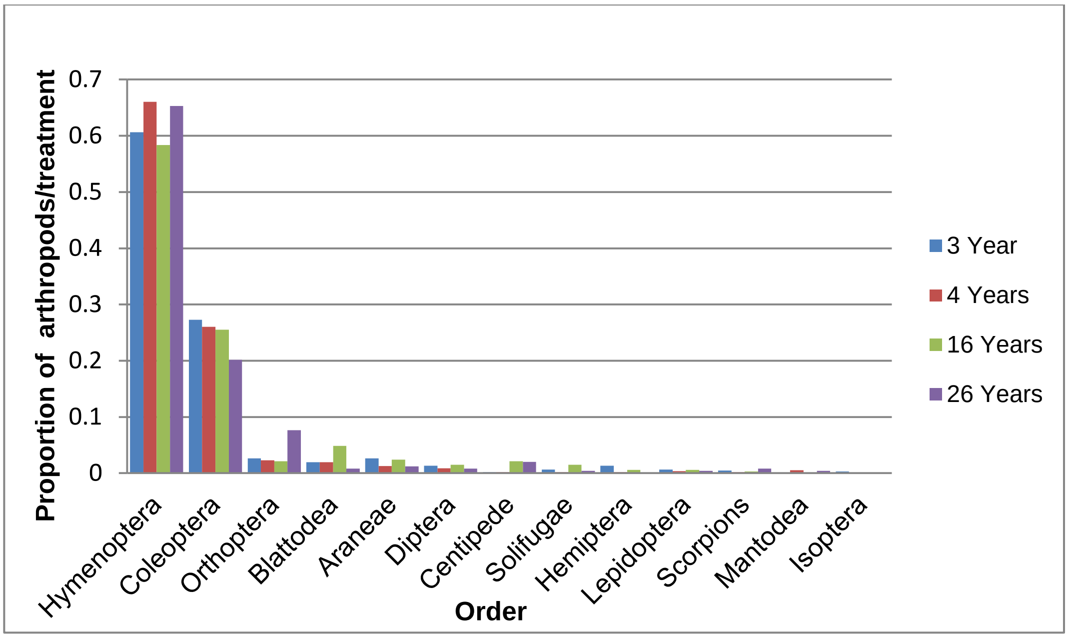


Figure 5: Proportional abundance of arthropod orders per treatment

The above graph shows the same trend as (graph 4) with order Hymenoptera and Coleoptera dominating the four fire treatments. The abundance of order Hymenoptera among the treatments was higher compared to other orders; however there was no distinct variation in Hymenoptera abundance among the treatments.

Table 2: Total capture (Morpho species) of arthropod taxa obtained from pitfall traps from four fire treatments with different fire histories at Waterberg Plateau Park (Namibia).

Order	Common Names	**Total species**	**3 Years**	**4 Years**	**16 Years**	**26 Years**
Araneae	Spiders	7	4	5	4	3
Blattodea	Cockroaches	2	2	1	2	1
Centipede	Centipedes	2	1	1	2	2
Coleoptera	Beetles	26	15	17	14	12
Diptera	Flies	6	4	3	3	1
Hemiptera	Bugs	7	4	1	2	0
Hymenoptera	Ants, Bees, Wasps	25	18	15	12	11
Isoptera	Termites	2	2	0	0	0
Lepidoptera	Butterflies & Moths	3	1	1	1	1
Mantodea	Mantids	2	0	2	0	1
Orthoptera	Crickets, Grasshoppers & Locusts	10	4	5	6	4
Scorpiones	Scorpions	3	2	1	1	2
Solifugae	Solifuges	4	3	1	3	1
Totals		**99**	**60**	**53**	**50**	**39**

4.1. OVERALL GROUND DWELLING ARTHROPODS ABUNDANCE

Abundance declined significantly with increasing in time since last burn (F= 5.538, df= 3, P<0.05, n=6). Treatment burned 3 years ago had higher abundance compared to other fire treatments followed by treatment burned 4 years ago and they were significantly different from the treatment burned16 and 26 years ago(Figure 6).

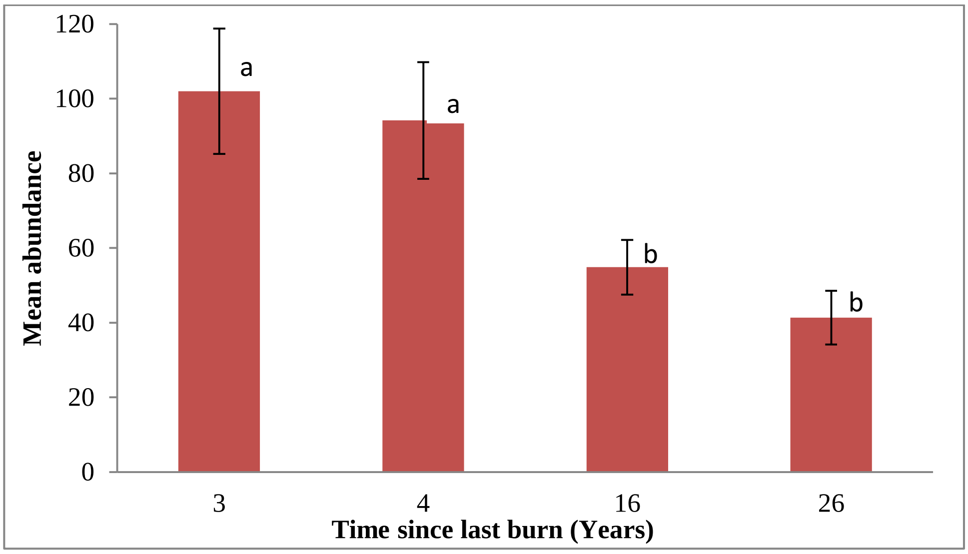


Figure 6: Mean ground dwelling arthropod abundance

4.2. OVERALL GROUND DWELLING ARTHROPOD DIVERSITY

SHANNON DIVERSITY

There was there was no statistical significant difference of Shannon diversity among the treatments (df= 3, p>0.05, n=6)

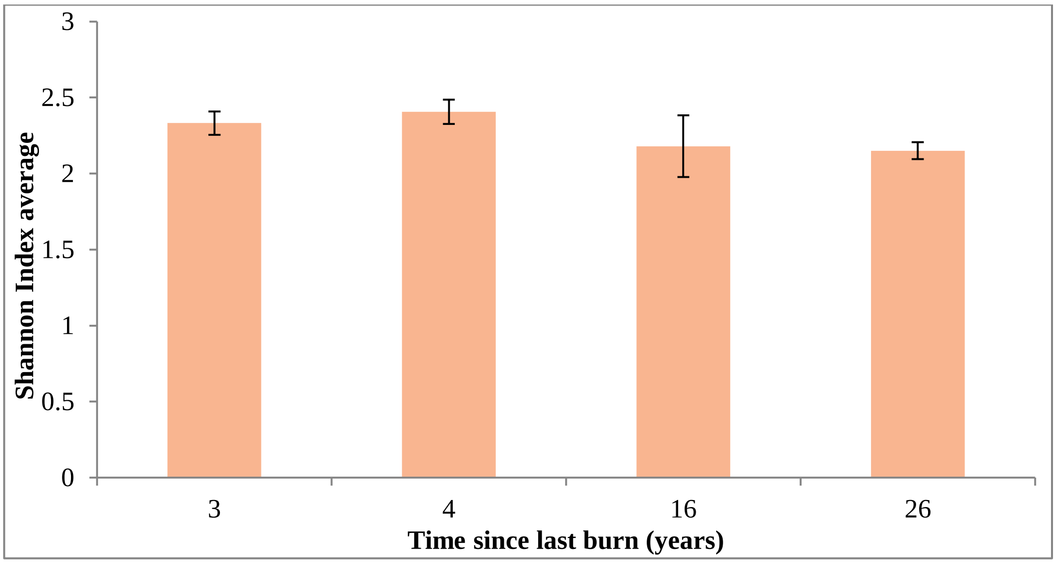


Figure 7: Mean Shannon diversity in relation to time since last burn

SPECIES RICHNESS

Species richness declined significantly with increasing in time since last burn. The fire treatment burned 3 years ago had higher species richness compared to the fire treatment burned 26 years ago (F= 2.962, df= 3, P<0.05, n=6) (Figure 6).

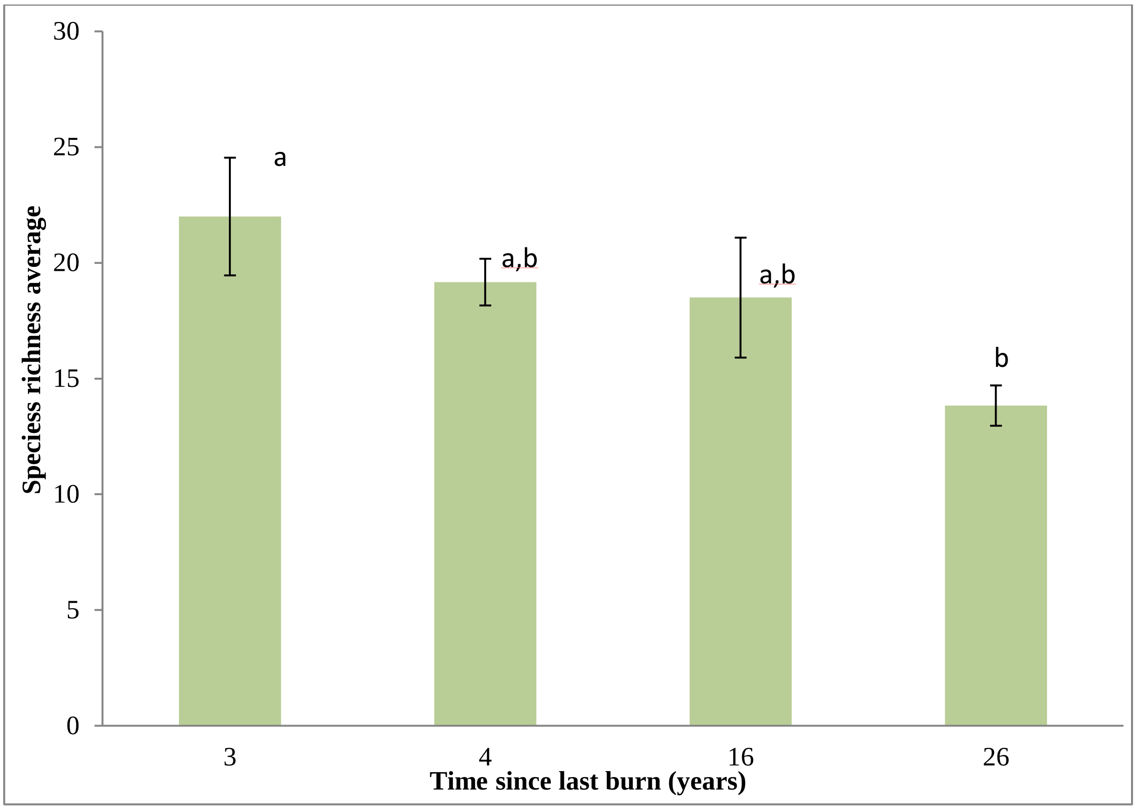


Figure 8: Mean species richness in relation to time since last burn

4.3. SPECIES COMPOSITION

ORDINATION

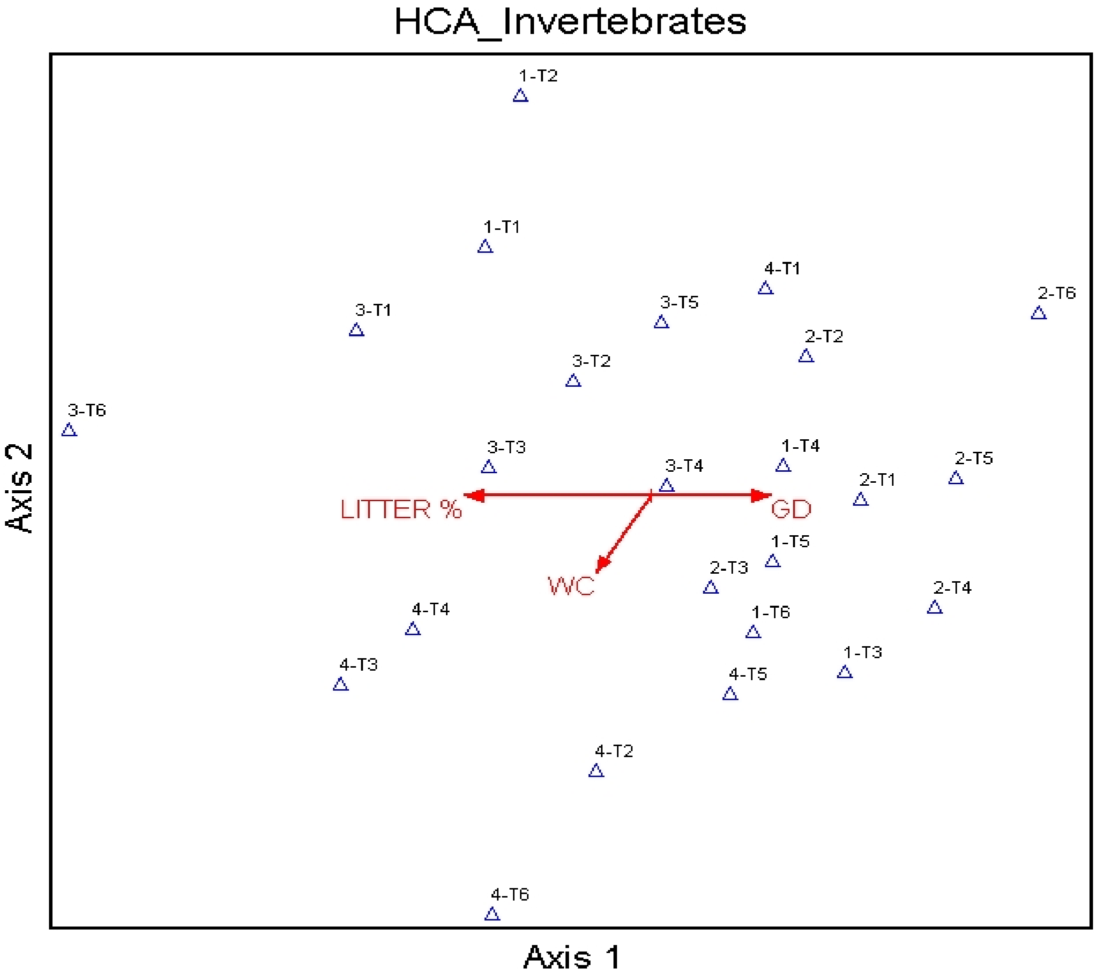


Figure 9: NMS joint plot for invertebrates (ground dwelling) morpho-species composition in relation to various environmental variables at r2 cut off= 0.2. The numbers denote the treatments: 1= 3, 2= 4, 3= 16 and 4= 26, while the letter & number represent the transect numbers, i.e. T1= transect 1.

NMS grouped the treatments together, however transect 1and 2 of treatment 1 were grouped far from the rest of treatment 1(seems to be outliers), so the ground dwelling arthropods composition in those transects is somehow different to other transects of the same treatment.

The NMS ordination results below revealed that litter; grass density and woody cover other than fire are the driving factors of invertebrates (ground dwelling arthropods) morpho species composition. Litter was the strongest driving variable, with the effect more towards treatment burned 16 and 26 years ago.

4.4. DOMINANT SPECIES

Due to the inconsistency of the results across different orders of arthropods, the study dwelled into the dominant families: Formicidae(Ants), Tenebrionidae, Scarabidae, Carabidae and one order Orthoptera.

Ants overall species richness declined with increasing in time since last burn (Figure 10)

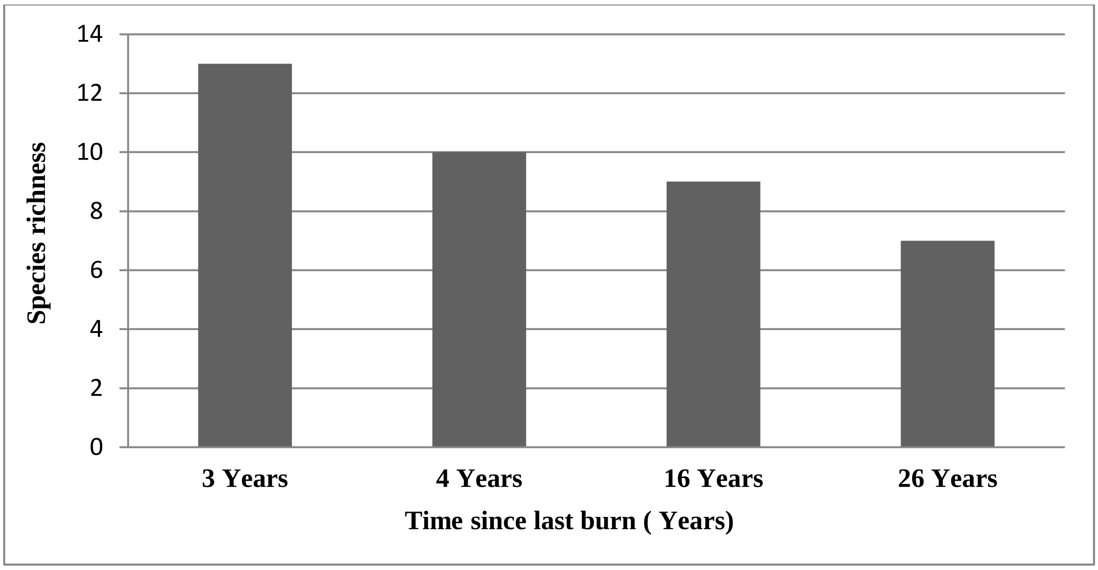


Figure 10: Overall species richness of Ants per treatment

For the beetles, Tenebrionidae species richness increased with increasing in time since last burn, Scarabidae species richness decreased in treatment 16 and 26 and Carabidae species richness remained the same in treatment 3, 4 & 16 and declined in treatment 26.

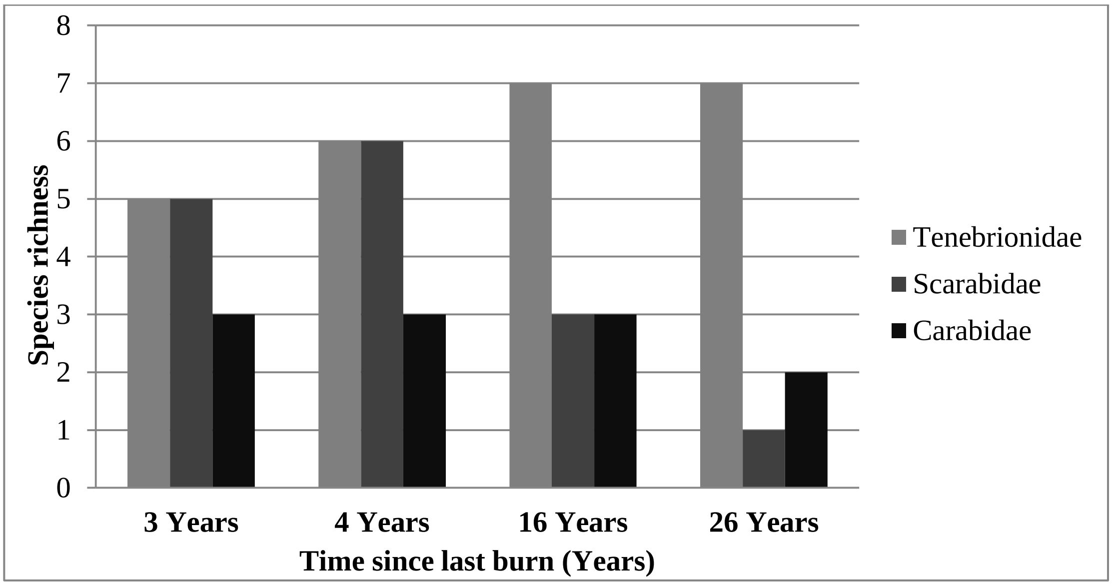
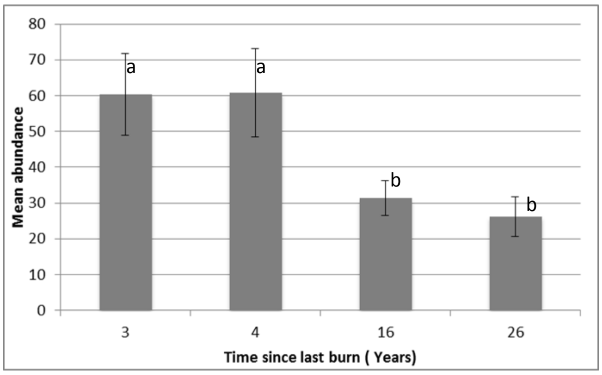


Figure 11: Overall species richness of 3 families of beetles per treatment

Abundance of ants declined significantly with time since last burn (F= 4.069, df= 3, P<0.05, n=6). Treatment burned 3 years ago had higher abundance compared to other fire treatments followed by treatment burned 4 years ago and they were significantly different from the treatment burned 26 years ago(Figure 12). Ant species richness declined with increasing time since last burn (figure 13); however there was no significant difference in Ants species richness among the treatments (F= 2.39, df= 3, p>0.05, n=6).



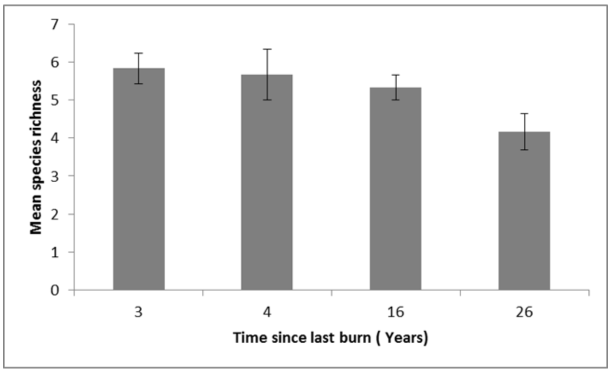
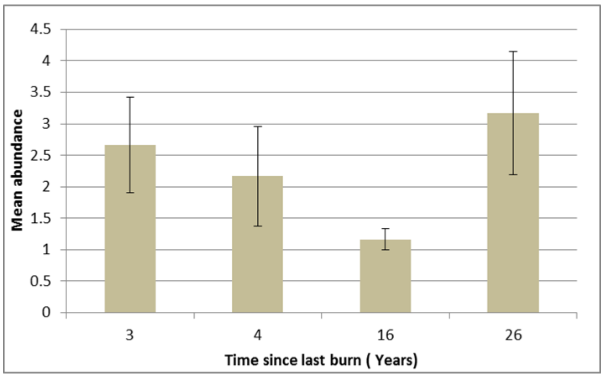


Figure 12: Mean abundance of ants per transect in each treatment

Figure 13: Mean species richness of ants per transect in each treatment

Although order Orthoptera had a total morpho species richness of 10 (Table 2), statistically there was no significant difference in terms of abundance (F= 4.37, df= 3, p>0.05, n=6, Figure 14) and species richness (F= 0.44, df= 3, p>0.05, n=6, Figure 15) among the fire treatments



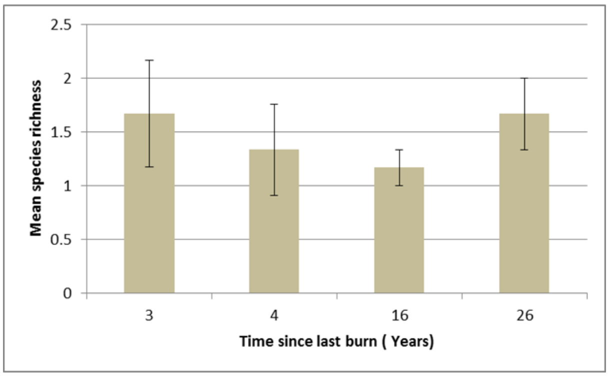


Figure 14 Mean abundance of Orthoptera per transect in each treatment

Figure 15: Mean species richness of Orthoptera per transect in treatments

Abundance of Tenebrionidae declined significantly with increasing time since last burn (F= 4.45, df= 3, P<0.05, n=6). Treatment burned 3 years ago had higher abundance compared to other fire treatments followed by treatment burned 4 years ago and they were significantly different from the treatment burned 26 years ago(Figure 16). Tenebrionidae species richness increased with increasing time since last burn (figure 17); however there was no statistical significant difference in Tenebrionidae species richness among the treatments (F= 0.08, df= 3, p>0.05, n=6).

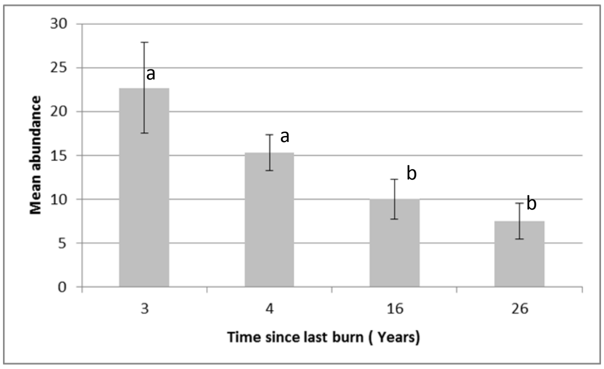


Figure 16: Mean abundance of Tenebrionidae per transect in treatments

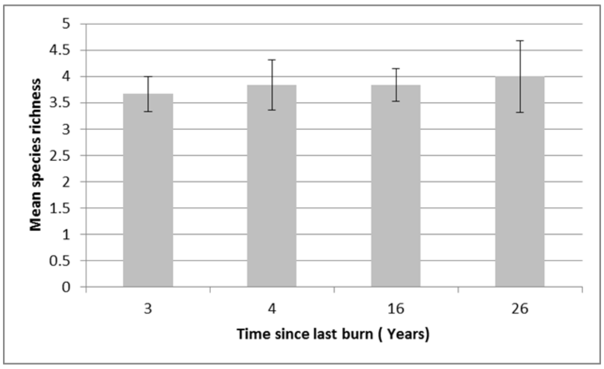


Figure 17: Mean abundance of Tenebrionidae per transect in treatments

There was a higher abundance and species richness of Scarabidae beetles in treatment 4 compared to other treatments, however statistically there was no significant difference in abundance (F= 2.04, df= 3, p>0.05, n=6, Figure 18) and species richness (F= 1.19, df= 3, p>0.05, n=6, Figure 19) among the fire treatments.

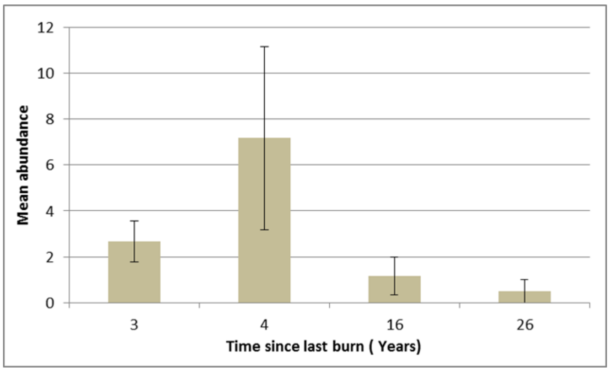


Figure 18: Mean abundance of Scarabidae per transect in treatments

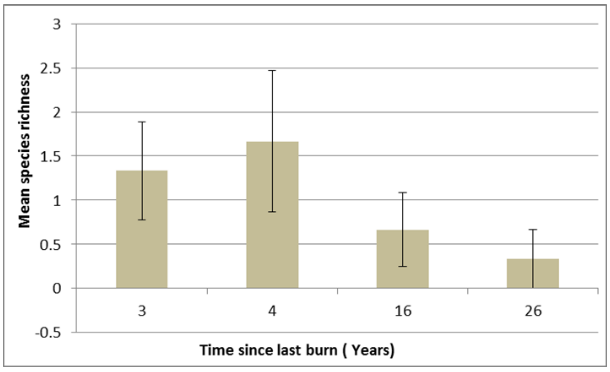
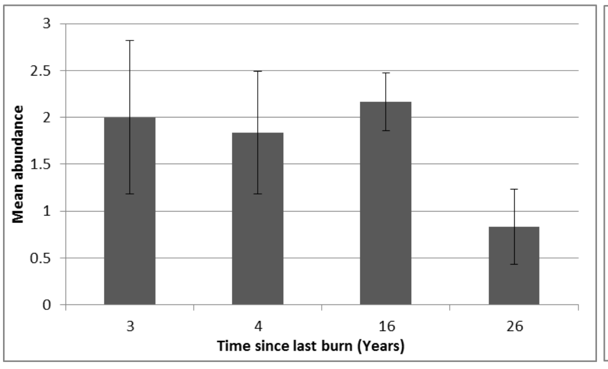


Figure 19: Mean species richness of Scarabidae per transect in treatments

There was no trend in terms of abundance and species richness of Carabidae bettles among the treatments. Again, there was no statistical significant in terms of abundance (F= 1.06, df= 3, $p>0.05$, $n=6$, Figure 20) and species richness (F= 1.09, df= 3, $p>0.05$, $n=6$, Figure 21) among the fire treatments.



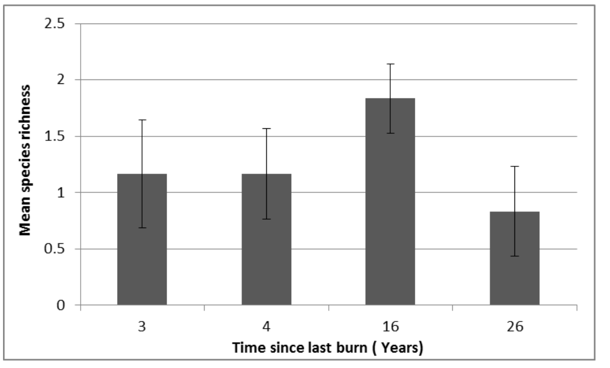


Figure 20: : Mean abundance of Carabidae per transect in each treatment

Figure 21: Mean species richness of Carabidae per transect in each treatment

5. DISCUSSION

This study analysed the impacts of fire on four distinct aspects of the ground-dwelling arthropods: Shannon diversity, species richness, species composition and abundance in four different treatments with different time since last burn. Two of the most important limitations of this study are 1). Effects of fire history on ground dwelling arthropods is one of the under studied topic in savanna ecosystem, making it difficult to relate and discuss our findings to those of that did it in the same ecosystem. 2). Most of the studies done in similar ecosystems looked mostly at responses of single ground dwelling arthropod species to fire and comparing it with controls and mostly annual burns with controls and not under different fire regimes.

Swengel (2001) reported that species in systems with long fire intervals of 20 years or more may react differently to fire effects, with richness and abundance declining after at least 7–15 years after fire. This was similar to what our study found; a significant decline with increasing in time since last burn on arthropods overall abundance and species richness among the treatments and which was the same with the study done by Anderson & Muller (2000) in Southern Australian savannas. This could be because of different variables in post-fire events that are difficult to predict and are greatly influenced by species interaction, resources, and habitat structure (Joern and Laws, 2013).

From this study, the Shannon diversity was unaffected by burning , these findings were similar to those of Siemann, Haarstad & Tilman (1997) that reported that there was an insignificant change in the arthropod Shannon diversity between the burnt and the unburnt areas. The statistical difference in the diversity of the arthropods in our study remained small recording nearly similar values among the treatments.

Arthropod species composition revealed that litter was the main driving variable with a significant effect towards treatment burned 16 and 26 years ago. Although it was not statistically significant, species richness of Tenebrionidae (litter loving beetles) increased with increasing in time since last burn, more in treatment burned 16 and 26 years ago compared to treatment burned 3 and 4 years ago had. This could be the reason as to why the strong litter effect. Evans (1984) has reported that areas with similar burning histories may have similar arthropod species compositions, but our results do not clearly support or reject this conclusion.

For dominant species, Ants abundance and species richness decreased with increasing in time since last burn, more in treatment burned 3 and 4 years compared to treatment burned 16 and 26 years. Ants are said to be indicators of disturbance (Parr et al 2004) as they flourish and become abundant in disturbed areas. Treatments burned 3 and 4 years are still recovering from fire so they can be described as disturbed.

For the beetle's families, Tenebrionidae abundance declined significantly with increasing in time since last burn. They were more abundant in treatment burned 3 and 4 years ago compared to the treatments burned 16 and 26 years ago. There was a higher abundance and species richness (not statistically significant) of Scarabidae beetles in treatment 4 compared to other treatments. Uunona, (2014) found that, with sufficient moisture, a diversity of large mammals in recently burned areas attracts a diversity of dung beetles. Generally, our study had very low numbers of Scarabidae (dung beetles) compared to Tenebrionidae and the study area had poor rainfall for the past season (296.19 mm as opposed to 811.39 mm of July 2013 to August 2014) which maybe was not sufficient for dung beetles and other arthropods (in low numbers) to persist in high numbers. There was less abundance of dung beetles in treatment 3 compared to 4, but a statistically significant abundance of Tenebrionidae which are generally said to be detritivores but can feed on dung too (www.bugguide.com). Tenebrionidae could be attracted to dung also thus why the higher abundance in treatments burned 3 and 4 years ago. Orthoptera and Carabidae abudance and species richness was inconsistent among the treatment with no clear and unexplainable trends.

Lastly, our different results of the effects of time since last burn on ground dwelling arthropod diversity at the Waterberg plateau Park perhaps could be because we don't know the season when fire occurred and how intense the fire was in all treatments. We do not know much about these factors and how they may influence the ground dwelling invertebrates.

6. CONCLUSION

Current fire regime has inconsistent and little effects on overall ground dwelling arthropods Shannon diversity but has clear trends (decline with increasing in time since last burn) on overall ground dwelling arthropods abundance and species richness.

For abundant groups, there was a decrease in ant species abundance & richness with increasing in time since last burn, suggesting that for ant's species richness some species "dropped" out as the time after last fire increases. There was an increase in Tenebrionidae species richness (although it was not statistically significant across the treatments) with increasing in time since last burn and a significant decline with an increasing in time since last fire in Tenebrionidae abundance. For species richness, this suggests that Tenebrionidae species are "added" as the time after last fire increases.

There was a decrease (not statistically significant) in Scarabidae (dung beetles) species richness with an increase in time since last fire, suggesting that some dung beetles species “drop out” with increasing in time since last fire. Carabidae abundance and species richness remained fairly the same in treatment burned 3, 4 & 16 years ago and declined in treatment 26.

For species composition, litter (secondary effect of fire) was revealed to be the strongest driving variable for ground dwelling arthropods composition with a strong effect toward treatment burned 16 and 26 years ago. There were low similarities among the treatments but not all species were a subset of similar species in other treatments, some species were unique in different treatments so each fire treatment at Waterberg Plateau Park is important and unique in terms of ground dwelling arthropods species composition. The management at the Waterberg Plateau Park should conserve all treatments to maximise beta diversity

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9. APPENDIX A

Journal of Entomology and Zoology studies – Author Guidelines

The manuscript should be prepared in English using "MS Word". "Times New Roman" font should be used. The font size should be of 12pt. All research articles should have the following sections: Title page, Abstract, Key words, Introduction, Materials and methods, Results, Discussion, Conclusion, Acknowledgement (if any) and References.

Title: The title should then followed by the author name and the institution name and address by indicating suitable superscripts. An asterisk (*) must be placed after the corresponding authors name. Corresponding author has the responsibility to ensure that all co-authors are aware and approve the contents of the submitted manuscript. It is required to submit email id, fax and telephone number of all authors.

Abstract: This section should detail the problems, experimental approach, major findings and conclusion in one paragraph. Avoid abbreviation, diagram and references in the abstract. It should be single - spaced and should not exceed 150 words for full papers.

Keywords: Author(s) must give about 4-6 key words which can identify the most important subjects covered by the paper. They must be placed at the end of the abstract.

Introduction: The manuscript should include a brief introduction stating the purpose of the investigation and relating the manuscript to similar previous research. Only information essential to the arguments should be presented.

Materials and Methods: This section must contain specific details about the materials studied, instruments used, specialized chemicals source and related experimental details which allows other research worker to reproduce the results.

Results and Discussions: The results should be concisely presented. Results and discussion may be separate or combined based on the author's requirement. Tables and figures should be designed to maximize the comprehension of the experimental data. The interpreted results should be explained clearly in discussions and should relate them to the existing knowledge in the field as clearly as possible. Tables, Graphs and figures (Illustrations) should be inserted in to the main text at respective place they should appear when published and should have appropriate numbers and titles with an explanatory heading. Labels of the table, graph and figures MUST be in the text form and should not form part of the image. Those photographs must be clear and sharp. Digital files are recommended for highest quality reproduction.

Acknowledgement (if any): This section can be kept at the end of the manuscript before reference section. This section can be used to acknowledge the help of those who do not qualify for authorship or to acknowledge funding, donated resources or significant contribution to the research.

References: References to the literature cited for the manuscript should be numbered in order of appearance in the manuscript and cited in the text with superscript numbers