Responses of ground-dwelling arthropods to long-term prescribed fire regimes in a savanna protected area.

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Research Article

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Abstract

Background

Sound management of protected areas is crucial for biodiversity conservation. In savanna systems, fire is common, yet little is known on the direct and long-term effects of prescribed burns on arthropod abundance, richness, and diversity. Standardised pitfall traps and active searches were used to compare variation in abundance, richness and diversity of arthropods at various experimental burn plots in the Kruger National Park, a protected area in a savanna setting.

Results

Hymenopterans: Formicidae were the most abundant (76.4%), whilst Coleopterans, Araneae and Orthopterans constituted 18.6, 3 and 1% of the total arthropods collected respectively. Coleopterans were the most diverse group (30.2%) compared to Hymenopterans: Formicidae (24.6), Araneae (24.6) and Orthopterans (4%). Abundance, species richness and diversity of multi-taxa significantly differed between the treatment plots. Abundance and diversity of Formicidae were significantly lower, hence, species richness was significantly higher in annually burnt plots compared to the unburnt control plots. Although the highest number of arthropods was recorded in unburnt plots, species richness and diversity were lowest in these plots compared to those burnt annually and triennially.

Conclusions

We conclude that late summer burns do not have major ecological impact on arthropods, and it was demonstrated by the abundance and diversity of species recorded at the annually burnt plots. Thus, annual late summer burns can be used as a conservation tool for arthropod inhabiting the protected savanna of Kruger National Park.

1. Introduction

The savanna biome is a landscape dominated by grasses and scattered trees (Scholes & Archer, 1997). Globally, savannas sustain diverse plants, vertebrates, invertebrates and pathogenic species (Botha et al., 2016; Leeuwis et al., 2018; Vaz et al., 2012). In South Africa, this biome has been identified as the largest landscape, covering more than one-third of the total land surface area (Low & Rebelo, 1998). The landscape is amongst known species-rich ecosystem which is highly sensitive to disturbances and changes in the composition of one or more communities in the food-web affects the abundance of other inhabitants and functioning of this ecosystem (Layme et al., 2004; Low & Rebelo, 1996; Mbenoun et al., 2017; Siemann et al., 1997; Soto-Shoender et al., 2018; Uehara-Prado et al., 2010). This may lead to the dysfunctional and imbalanced ecosystem thus compromising the provision of essential ecological services.

Arthropods are the most dominant group of organisms in savannas and are sensitive to ecological changes (Blaum et al., 2009; Botha et al., 2016; LeClare et al., 2020). They account for more than 80% of the identified species from the Animalia Kingdom (Friend & Richardson, 1986; Stork, 2018). Their contribution towards ecosystem services include organic matter decomposition, nutrient cycling, pollination, seed dispersal, maintenance of biome density and food resource for other organisms within savanna landscapes (Botha et al., 2016; Del-Claro et al., 2019; Kunz & Krell, 2011; LeClare et al., 2020). However, arthropod abundance, richness and composition are affected by anthropogenic disturbances and climate change (Gebeyehu & Samways, 2003; Jerrentrup et al., 2014; Mauda et al., 2018; Parr et al., 2012). Changes in the composition of species within savanna ecosystems does not only interrupt the ecological processes and functions, but also disrupts trophic interactions (Maia et al., 2019; Mauda et al., 2018; Scheiter et al., 2019).

The common disturbances within savanna ecosystems include mammal herbivory/ grazing, fuelwood extraction and veld fires (Andersen & Mũller, 2000; Butler et al., 2021; Mograbi et al., 2019; Siemann et al., 1997). Although these three activities exert pressure on the composition of plants and arthropods, fire has been widely used to maintain the balance between the coexisting plant communities by impeding the dense encroachment of shady tree species but also promote coppicing of ground covering grass species and forbs. Thus fire, plays a pivotal role in savanna community assembly and subsequent ecosystem function (Butler et al., 2021; Coetsee et al., 2010; Higgins et al., 2000; Smith et al., 2013; Trollope, 1980; Trollope et al., 1998). The influence of fires on the diversity of organisms, particularly arthropods and ecosystem processes in savanna biomes has received minimal attention. Yet, this knowledge is crucial in the conservation of biodiversity and management of protected conservancy reserves.

In South Africa, one of the largest protected areas, Kruger National Park (hereafter referred to as KNP), pioneered the long-term fire trials in 1954, following the amendment of the fire suppression policy in 1948 (Biggs et al., 2003; Van Wilgen et al., 2004). The Experimental Burnt Plots (EBPs) were initiated with the intention of documenting the impact of fire on fauna and flora of a savanna ecosystem. However, the response of arthropods to different fire frequencies and intensities has received less attention (D'Souza et al., 2021; Horak et al., 2006; Parr et al., 2004; Wittkuhn et al., 2011).

Several studies have reported that less mobile ground-dwelling and flightless developmental stages of arthropods are prone to fires, while active and soil-nesting arthropods may endure fires (Butler et al., 2021; Certini et al., 2021; Higgins et al., 2014; Thom et al., 2015; Warren et al., 1987). Furthermore, the elimination of plants by direct fire affects the arthropods inhabiting and feeding on the eliminated plants and these impacts cascade through the food-chain (Haddad et al., 2009). Therefore, this study aimed at quantifying the long-term impacts of prescribed fires on the abundance, species richness and diversity of arthropods within the EBPs of the KNP. We hypothesized that long-term prescribed burns (annual and triennial) affected the abundance, species richness and diversity of arthropods in KNP.

2. Material And Methods

2.1. Study area

Kruger National Park is the largest protected area (i.e., ~ 2 million ha) in South Africa and is located along the north-eastern boarder of the country. The park extends from Mpumalanga to Limpopo provinces, with its northern demarcation bordering Mozambique and Zimbabwe. The park is located in a subtropical region with the annual rainfall ranging between 350 and 750 mm per annum along the geographic regions dominated by granite and basalt soils. Furthermore, the monthly minimum and maximum temperatures of 15.7°C and 28.0°C was recorded during the cooler winter (June–August) and warmer summer (December–March) season, respectively (Zambatis, 2006). Furthermore, the dominating trees include *Acacia*, *Combretum*, *Sclerocarya* and *Colophospermum* (Biggs et al., 2003; Smith et al., 2013). Amongst the selected long-term experimental burnt plots is the Tsende (23° 27.319’S; 31° 23.197’E; 370 m a.s.l) and Skukuza (25° 5.870’S; 31° 27.891’E; 430 m a.s.l), which are located in the northern and southern parts of KNP, respectively (Fig. 1).

2.2 Experimental plots

The long-term Experimental burn plot (EBP) strings constituted twelve plots prior to the division of late summer biennial and triennial plots that were done with the intention of introducing the spring quadrennial and sexennial treatments in the late 1970s. The division resulted in the number of subplots increasing to fourteen at Tsende (Biggs et al., 2003). However, the two new treatments were not used in this experiment, rather the long-term plots established in 1954 namely, unburnt, annually- and triennially burnt during the late summer season (i.e., February- March) were used for arthropod sampling.

2.2. Arthropod sampling

A combination of passive and active arthropods capturing techniques were used to optimize the sampling effort of arthropods from different taxa following previous studies (Eckert, 2017; Garcia et al., 1982; Yekwayo et al., 2018). In brief, arthropods were first collected using pitfall traps and later active searches within the transects during the cool season (between June and July 2019). At each of the 100 m transects, ten pitfall traps were temporarily laid at a 2 × 5 grid transect with a trap-set (two individual pitfall traps) placed 2 m apart (Munyai & Foord, 2015). The first pair of pitfall traps were placed at least 20 m from the fire break to avoid the boundary effect. The distance between pitfall traps was maintained at 20 m and the experiment was replicated three times for each of the unburnt, annually- and triennially burnt plots (Ward et al., 2001). During sampling, a 500 ml plastic honey jar (8 cm diameter and 10 cm height) was buried with its rim flushing the soil surface. The jar was half-filled with ethylene glycol and the traps were left open during arthropod sampling for five consecutive days (Borgelt & New, 2006). Traps were removed after sampling to avoid destruction by the small and large mammals of KNP. The holes were closed with the soil to allow initial soil, biodiversity and biome recovery. Intensive active searches were conducted within the 100 x 2 m transect for 45 minutes. The less mobile arthropods inhabiting the dung, dwelling under rocks and those inhabiting specific host-plants where actively captured (Yekwayo et al., 2018). Data collected through both methods were pooled for each transect.

Muddy and other contaminated samples were washed prior to arthropods preservation. Collected arthropods were transferred from ethylene glycol to 70% ethanol and preserved at the University of Mpumalanga laboratory, Mbombela, South Africa for subsequent identification. In the laboratory, representative specimens were sorted and identified to the lowest taxonomic level (either morphospecies, genus or species) using guides by Picker (2012). The voucher specimens were housed and catalogued at the University of Mpumalanga, Biocontrol and Applied Entomology laboratory.

2.3. Data analyses

Data analyses were performed using Paleontological statistics software (PAST) version 4.09 (Hammer et al., 2001) and Statistica version 13.3 (TIBCO Statistica™). Non-parametric estimators were used to predict the asymptotic arthropod species richness for each of the annually, triennially burnt and unburnt plots separately, and for all plots combined. The robust, accurate and reliable coverage-based estimator of species richness namely incidence-based Coverage Estimator (ICE) was used to measure adequacy of sampling effort. Furthermore, Chao1, Chao2, Jacknife2 and Michaelis–Menten means estimators were used to provide the least-biased estimates of the sampled arthropods (Gotelli & Colwell, 2011). Estimators were calculated for each of the annual, triennial and unburnt plots separately and for all plots combined using EstimateS version 9.1.0 (Colwell 2006; Colwell 2013). The samples were randomized 100 times.

Due to the failure of the abundance and richness data to meet the assumptions of normality after multiple transformations, differences in abundance and species richness between plots were compared using the Kruskal-Wallis one-way Analysis of Variance (ANOVA) while One- way ANOVA was performed for Shannon diversity indices across plots. Comparisons were performed for multi-taxon and each of the four most abundant groups of arthropods.

Lastly, emulating species composition was calculated using the most abundant indicator species to test for similarity in species composition between unburnt, triennially and annually burnt plots (Hart et al., 2014). To visualize the separation of arthropod communities between unburnt, annually and triennially burnt plots, a non-metric multidimensional scaling (nMDS) was performed at a stress value of 0.07 and the Bray-Curtis distance was applied using Primer software.

3. Results

3.1. Species abundance and richness

A total of 6765 individual arthropods representing 126 morphospecies were collected from unburnt, annually, and triennially burnt plots at the protected area of KNP (Table 1). From the sampled arthropod species, Hymenoptera: Formicidae were the most dominating group, contributing 5168 (i.e., 76.4%) followed by Coleopterans 1255 (i.e., 18.6%), while 342 (e.g., 5.1%) individual arthropods were recorded from the remaining groups namely Orthopterans, Araneae, Blattodea, Dipterans, Hemipterans, Lepidopterans, Scorpiones, Spirostreptida, and Scolopendromorpha (Fig. 2). The highest number of arthropods was captured at the unburnt plots with a total 2532 (e.g., 37.4%). Furthermore, the abundance of multi-taxon declined by 0.9 and 0.7 folds at triennially and annually burnt compared to the unburnt plot, thus, a total of 2391 (e.g., 35.4%) and 1842 (e.g., 27.2%) arthropods were captured from each plot respectively (Table 1).

Table 1
Abundance, species richness and estimators of arthropods sampled from annually, triennially burnt and unburnt plots in the long-term experimental burnt plots of Kruger National Park.

Arthropod species	**Frequency of burns**			
	Annual	**Triennial**	**Unburnt**	**Combined**
Number of arthropods sampled	1842	2391	2532	6765
Percentage of arthropods sampled	27,2	35,3	37,4	100
Number of species sampled	87	65	69	126
Percentage of species sampled	69,1%	51,6%	54,8%	100%
ICE	117,8	73,7	93,4	169
Chao2	110,8 ± 11,4	69,6 ± 3,7	93,6 ± 13,1	161,3 ± 14.7
Jackknife2	129,3	76,04	107,3	184,7
Bootstramp	100.7	71.7	78	144.2
MM means	104.6	78.2	83.5	132.2
Estimators: ICE- incidence-based Coverage Estimator; MM means- Michaelis–Menten means				

The abundance of arthropods collected at the annually burnt plot was significantly lower (H = 7.528, df = 2, p = 0.023) compared to those at the unburnt plots. Nevertheless, there was no significant difference in abundance between triennially burnt and unburnt plots (Fig. 3; Table 2). Separate analyses on the response of key arthropod groups to long-term prescribed burning showed that the abundance of Hymenoptera: Formicidae (H = 7.906, df = 2, p = 0.019) significantly differed across plots (Fig. 4; Table 2), while, the abundance of Coleopterans (H = 0.9473, df = 2, p = 0.623), Orthopterans (H = 3.027, df = 2, p = 0.220), and Araneae (H = 1.707, df = 2, p = 0.427) was not statistically different between the annually, triennially burnt and unburnt EBPs.

Table 2
Multiple comparisons of the abundance of multi-taxon and Hymenoptera: Formicidae between annually, triennially burnt and unburnt Experimental Burnt Plots at KNP.

Group of arthropod(s)	Experimental burnt plots		Statistics*		
	A	B	*N*	*Z- value*	P- value
Multi-taxon	Annual	Triennial	18	2.1630	0.0916
		Unburnt	18	**2.5415**	**0.0331**
	Triennial	Unburnt	18	0.3785	1.000
Hymenoptera: Formicidae	Annual	Triennial	18	1.5141	0.39
		Unburnt	18	**2.6226**	**0.026**
	Triennial	Unburnt	18	1.1085	0.803

*Superscript: bolded statistical results shows significant difference between paired treatments at $P = 0.05$

Despite the noticeably high abundance of arthropods sampled at the long-term EBPs of KNP, the species richness did not reach asymptotic estimations at the annually, triennially burnt and unburnt plots either solely or combined. Of 126 morphospecies collected, the highest number of species was recorded at the annually burnt plots. A total of 87 (e.g., 69.1%) morphospecies were captured at the annually burnt plots, hence, 65 (51.6%) and 69 (54.8%) morphospecies were recorded at the triennially burnt and unburnt plots, respectively (Table 1). From these plots, the overall number of morphospecies sampled was highest for Coleopterans (30.2%), Hymenoptera: Formicidae (24.6%), Araneae (24.6%), Blattodea (5.6%), and up to 4% was recorded for Dipterans, Hemipterans, Lepidopterans, Orthopterans, Scorpiones, Spirostreptida, and Scolopendromorpha (Fig. 5).

Species richness for multi-taxon was significantly higher ($H = 7.806$, df = 2, $p = 0.020$) at the annually burnt plot compared to triennially burnt and unburnt plots (Fig. 6; Table 3). It increased by 0.1 and 0.2 folds in triennially and annually burnt plots respectively. Similarly, the species richness of ants ($H = 7.042$; df = 2; $p = 0.030$) was significantly different between the annually, triennially burnt and unburnt plots (Fig. 7; Table 3), hence, the species richness of other arthropods such as, Coleopterans ($H = 2.348$, df = 2, $p = 0.309$), Orthopterans ($H = 2.083$, df = 2, $p = 0.353$), and Araneae ($H = 1.132$, df = 2, $p = 0.568$) did not significantly vary between the three EBPs (i.e., annually, triennially burnt and unburnt plots). Multiple comparisons showed that species richness of multi-taxon and Hymenoptera: Formicidae significantly differed between the annually burnt and unburnt plots, hence, no variation was recorded between triennial burnt plot and either of the annually burnt or unburnt plots (Table 3)

Table 3
Multiple comparisons on the species richness of multi-taxon and Hymenoptera: Formicidae between annually, triennially burnt and unburnt Experimental Burnt Plots at KNP.

Group of arthropod(s)	Experimental burnt plots		Statistics*		
	A	B	*N*	*Z- value*	P- value
Multi-taxon	Annual	Triennial	18	2.2170	0.0799
		Unburnt	18	**2.5685**	**0.0306**
	Triennial	Unburnt	18	0.3515	1.000
Hymenoptera: Formicidae	Annual	Triennial	18	1.5141	0.39
		Unburnt	18	**2.6226**	**0.026**
	Triennial	Unburnt	18	1.1085	0.803

*Superscript: bolded statistical results shows significant differences between paired treatments at $P = 0.05$

3.2. Diversity metrices

Shannon diversity index showed that there was significant variation ($P < 0.05$) in the diversity of multi-taxon (i.e., all arthropods combined), and for the most abundant group of arthropods (i.e., Hymenoptera: Formicidae) (Fig. 8; Table 4). However, there was no significant variation ($P > 0.05$) in the diversity of Coleopterans and Araneae between the annually, triennially burnt, and unburnt EBPs. Nevertheless, the diversity metrices for Orthopterans was not computed due to lack of sufficient data (Table 4). Of the 126 morphospecies of arthropods collected in the current study, 30.2% of the species were shared between the three plots. Less than 4.8% of the overall species were shared between burnt (i.e., either annual or triennial) and unburnt plots. The highest number of species (e.g., 7.1%) was shared between annually and triennially burnt plots. Lastly, 16.7%, 11.1% and 27% of the species were distinct to the unburnt, triennially and annually burnt plots, respectively (Supplementary Table 1).

Table 4
Diversity (Shannon_D1) of arthropods sampled at the annually, triennially burnt and unburnt plots at the long-term Experimental Burnt Plots of Kruger National Park.

Group(s) of arthropods	**Statistics**				
	SS	**DF**	**mean squares**	**F**	**P- value**
Hymenoptera: Formicidae	0.35092	2	0.17546	3.887	**0.043646**
Coleopterans	0.49573	2	0.24786	1.3366	0.292304
Orthopterans	-	-	-	-	-
Araneae	0.12658	2	0.06329	0.2167	0.807644
Multi-taxon	0.6769	2	0.3384	6.752	**0.008109**

*Superscript: denotes that statistical analysis was not conducted for a specific group of arthropods due to the missing variables.

3.3. Relationship between plots and arthropods

Cluster analysis identified 4 groups: *group 1* - annual 3, *group 2* – triennial 1–3, unburnt 1–3 and annual 1–2, *group 3* – unburnt 4–6 and triennial 4–6 and *group 4* – annual 4–6. (Fig. 8). Within *groups 2* and *3*, subgroups of similar taxa groupings were observed, for example in *group 3*, the unburnt 4–6 and triennial 4–6 formed different subgroups. However, a subgroup in *group 2*, had annual 1–2 and triennial 1 grouped together suggesting similarities (Fig. 9). Similarly, the two-dimensional representation of the *n*-MDS showed that the arthropod community in unburnt plots were separated from those of the annual and triennial burnt plots while there was an overlap between the triennial and annual plots (Fig. 10). The Formicidae 26 and Carabidae 8 from the Hymenoptera: Formicidae and Coleopteran groups of arthropods characterised the unburnt plots whereas, the Formicidae 30 and Gyrinidae 6 from the same groups were common in the triennial plots and Carabidae 10 (i.e., Coleopterans) was common in the annual plot (Fig. 10).

4. Discussion

In the current study, the data collected from the unburnt, triennially and annually burnt plots did not reach asymptote for individual treatments separately and combined. This postulates that sampling efforts were insufficient at each treatment plot separately and combined, however, the data was analysed to measure the variation in abundance, species richness and diversity of arthropods at the long-term experimental burnt plots of KNP. Similar studies conducted in grasslands, woody forests and savannas landscapes demonstrated clearer impact on the abundance, species richness and diversity of arthropods although the analysed data did not reach asymptote (Kunz & Krell, 2011; Magoba & Samways, 2012; Otieno et al., 2021). The studies demonstrated how prescribed fire can be an ecologically sound approach that balances the abundance, species richness, composition and diversity of arthropods in the forests, grasslands and oak savanna landscapes in the United State of America (Ferrenberg et al., 2006; Harper et al., 2000; Siemann et al., 1997). Likewise, the current study reports the significant impact of prescribed burns (i.e., annually and triennial) on the abundance, species richness, and diversity of sampled arthropods at the long-term experimental burnt plots of KNP, although the data did not reach asymptote.

The abundance, species richness and diversity of multi-taxa significantly differed between the annually burnt and unburnt plots while the triennially burnt did not differ with the unburnt treatment at the long-term EBPs of KNP. This variation may have been elicited by the prescribed burn that occurred a month before sampling in the annually burnt plots resulting in minimal recovery time. The current study showed that burning improves the richness and diversity of species whilst decreasing arthropod abundance at the burnt plots of KNP. The findings corroborate with previous studies that reported differences in abundance, species richness and diversity of arthropods after incidental/ prescribed fires in Europe, United states of America and Africa (Ferrenberg et al., 2006; Siemann et al., 1997; Valkó et al., 2016; Yekwayo et al., 2018). Of the plots sampled at KNP, the abundance, species richness and diversity was significantly different between the annually burnt (i.e., which was burnt approximately a month before the initial sampling) and the unburnt plot. Furthermore, no statistical variations was notable between the triennially burnt (i.e., burnt at least two years before arthropod sampling) and either the annually burnt or unburnt plots. Several studies showed that the abundance, richness and diversity of arthropods sampled at least 6 months (i.e., up to 10 years) after incidental or prescribed fires does not statistically differ with that on the unburnt plot at protected areas (Ferrenberg et al., 2006; Graham et al., 2009; Pryke & Samways, 2012; Valkó et al., 2016; Yekwayo et al., 2018). Since arthropods were sampled a month after burning at the annually burnt plots, we therefore speculate that the notable variation in abundance, species richness and diversity of multi-taxa arthropods might have been influenced by the time between the fire incidence and initial sampling (< 6 months). Given this variation, the results indicate that responses of arthropods are time-since-fire related.

Amongst the most abundant taxa sampled from the experimental burnt plots of KNP were Hymenoptera: Formicidae, Coleopterans and Araneae. This is in agreement with previous studies which reported the three groups of arthropods (i.e., Hymenoptera: Formicidae, Coleopterans and Araneae) as the most abundant arthropods sampled at sites where multi-taxon were used as ecological indicators to measure the impact of prescribed or incidental fires (Ferrenberg et al., 2006; Kaynas, 2016; Pryke & Samways, 2012; Valkó et al., 2016; Yekwayo et al., 2018). The abundance of Hymenoptera: Formicidae was not surprising since they are known to be ubiquitous group of insects contributing to a variety of ecological functions in grasslands and savannas (da Silva et al., 2020; Graham et al., 2009; Underwood & Fisher, 2006; Van Schalkwyk et al., 2019). Of the individual groups of arthropods sampled, only the most dominant taxon (i.e., Hymenoptera: Formicidae) was significantly affected by the frequency of burns at the protected savanna of KNP. This notable difference in the abundance, species richness and diversity reflect the sensitivity of Hymenoptera: Formicidae to prescribed fires. The sensitivity of Hymenoptera: Formicidae to ecological disturbances (i.e. fire) at the EBPs illustrates their renown use as a reliable ecological indicator.

The response (e.g., abundance, species richness and diversity) of the most abundant taxon (i.e., Hymenoptera: Formicidae) emulated that of the multi-taxa at different burning regimes at KNP. Likewise, Siemann et al. (1997) reported that the abundance, species richness and diversity of dominating group of arthropods was similar to that of multi-taxa combined at different burnt plots at the oak savanna of Cedar Creek Natural History Area, Minnesota. Moreover, Yekwayo et al. (2018) demonstrated that the abundance, species richness and diversity of the most abundant group of arthropod (i.e., Hymenoptera: Formicidae) was similar to that of the multi-taxon in a study which measured the impact of fire on arthropods at the Cape Winelands and Kogelberg Biosphere Reserves, Western Cape, South Africa.

The increase in the number of arthropods with the time post-fire and frequency of prescribed burns demonstrates the direct and indirect effect of fire on the ground dwelling arthropods at the KNP. The results showed that shortly after burn, the number of individual arthropods was significantly lower compared to numbers at plots burnt a year before sampling and the unburnt. However, species richness and biodiversity indices contrasted the arthropod abundance data, with statistically high richness and biodiversity at the annually burnt compared to triennially burnt and unburnt plots. These results corroborate with previous studies that reported benefits of fires on the composition of arthropods, although the numbers were drastically affected in the short term (Ferrenberg et al., 2006; Lazarina et al., 2017).

Ground-dwelling invertebrates and immature inhabiting combustible live (e.g., plants) or dead material (e.g., litter) are highly prone to fires and may be burnt during veld fires (Kwok & Eldridge, 2015; Kwok et al., 2016; Vasconcelos et al., 2009). As such, the destruction of various habitats such as plant, litter, dung during burning is speculated to have significantly reduced the numbers of arthropod at the annually burnt plots in the current study. While Yekwayo et al. (2018) reported lower species richness and diversity of arthropods, the current study reported otherwise in annually burnt plots. However, a study by Pryke and Samways (2012) reported that the diversity of multi-taxon is significantly higher at a recently burnt plot (i.e., 3-month post fire) compared to those sampled a year to three years after fires.

Underground nests and animal dung encouraged survival of ants and coprophagous beetles (i.e., Coleopterans) which appeared to be less than 2-folds lower in the annually burnt plot compared to triennially burnt and unburnt plots at KNP. Neither abundance, species richness and diversity of Coleopterans (i.e., dominated by coprophagous beetles) were affected by frequency of burns at KNP. Some studies demonstrated the resilience of coprophagous Coleopterans against incidental and veld fires and this has been associated with the dung and underground nesting behaviour of this specific group of arthropods (Nunes et al., 2019; Palusci et al., 2021). Although statistical variation was notable for Hymenoptera: Formicidae, the underground nests were speculated to have protected the scavenging ants from the direct fire. The insignificant impact on the assemblage of Orthopterans and Araneae is a result of overwintering strategy of some developmental stages below the soil surface and dispersal abilities of these groups (Jing & Kang, 2003; Lipovšek & Novak, 2016; Narimanov et al., 2021).

The current study shed some light on the long-term benefits of late summer prescribed burns on the conservation of arthropod species and biodiversity in the savanna landscape of KNP. Results on the long-term impact of late summer prescribed burns filled a gap outlined by Parr et al. (2004) which emphasized the need to assess the overall response of arthropods (i.e., multi-taxon) at the protected areas where late summer fires have been constantly used as a veld management tool. The current study reported that the impact of the late summer fire is temporal and the abundance of arthropods significantly improves with the time-since-fires. The rate recovery by arthropods emulates that incurred post-burn or incidental fires. Improved species richness and diversity at burnt plots elucidate the benefit of fire at the protected areas of Kruger National Park. In conclusion, burning during late summer season should be encouraged although it has temporal impact on the abundance of arthropods inhabiting savanna landscape of KNP. The intensity of ongoing prescribed burns at the protected reserve of KNP encouraged the conservation of arthropod species for over 67 years, thus, the disruption of functions and ecological services rendered by arthropods is temporal.

Declarations

Ethics approval and consent to participate.

Ethical clearance was provided by South African National Parks (Sanparks) Scientific Services Ref: MUKWL1570 to LM and the University of the Free State Ethics Approval Ref: UFS-AED2018/0078 to FC.

Consent for publication

All authors read and are in support of article submission and publication

Availability of data and material

Data is available on request

Competing interests

The authors declare no conflict of interest.

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Authors' contributions

Conceptualization: LM, FC, MN

Data curation: LM, FC

Formal analysis: LM, GC

Funding acquisition: FC, LM

Investigation: LM

Methodology: LM, FC, GC

Project administration: FC

Resources: FC

Supervision: FC, MN

Validation: FC, MN, TD

Visualization: GC, LM

Writing - original draft: LM, FO,

Writing, review & editing: LM, RM, GC, MN, FC, TD

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Figures

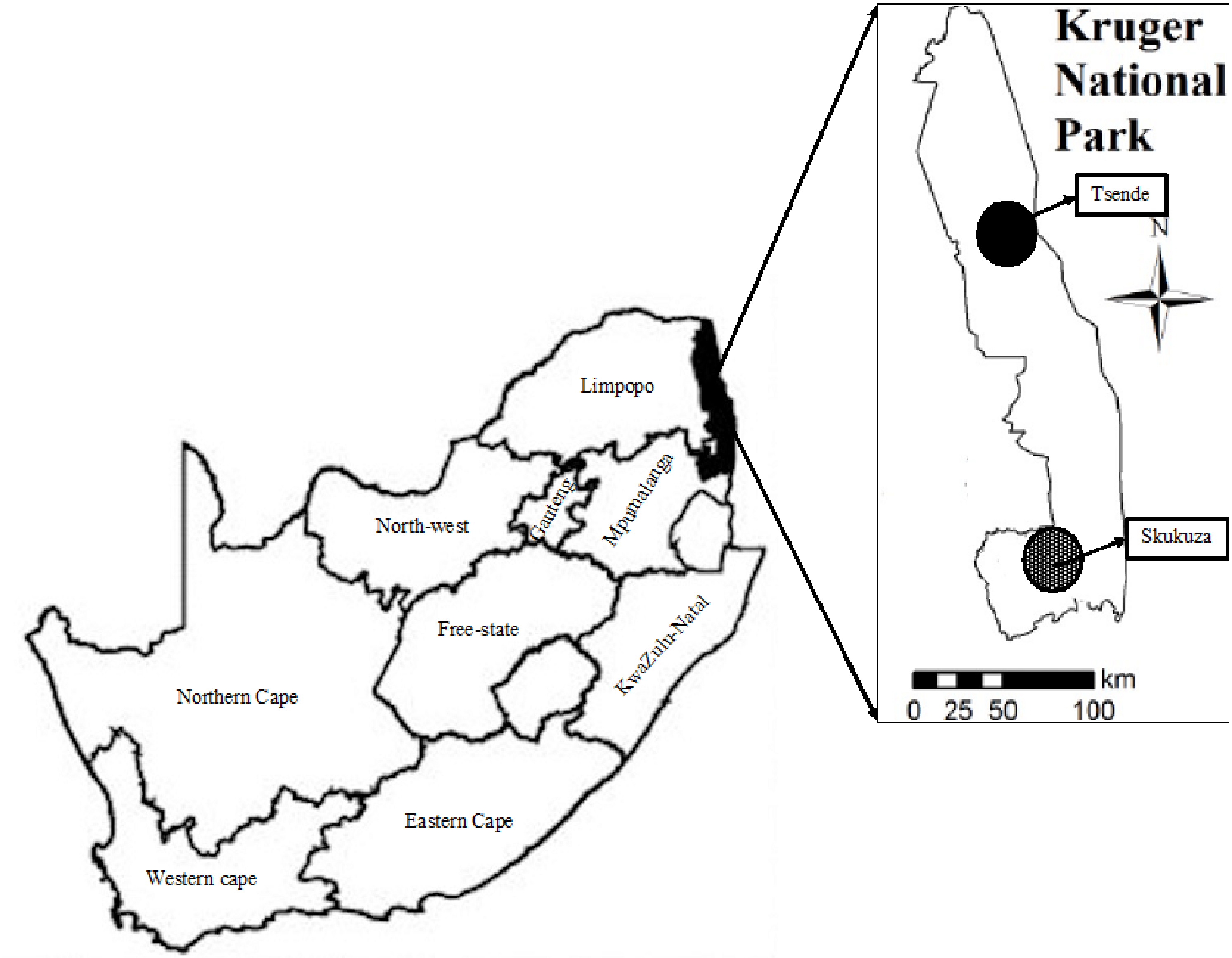

Figure 1

South African map displaying the geographic location of Kruger National Park and two selected experimental burnt plots namely Tsende (shaded circle) and Skukuza (dotted circle).

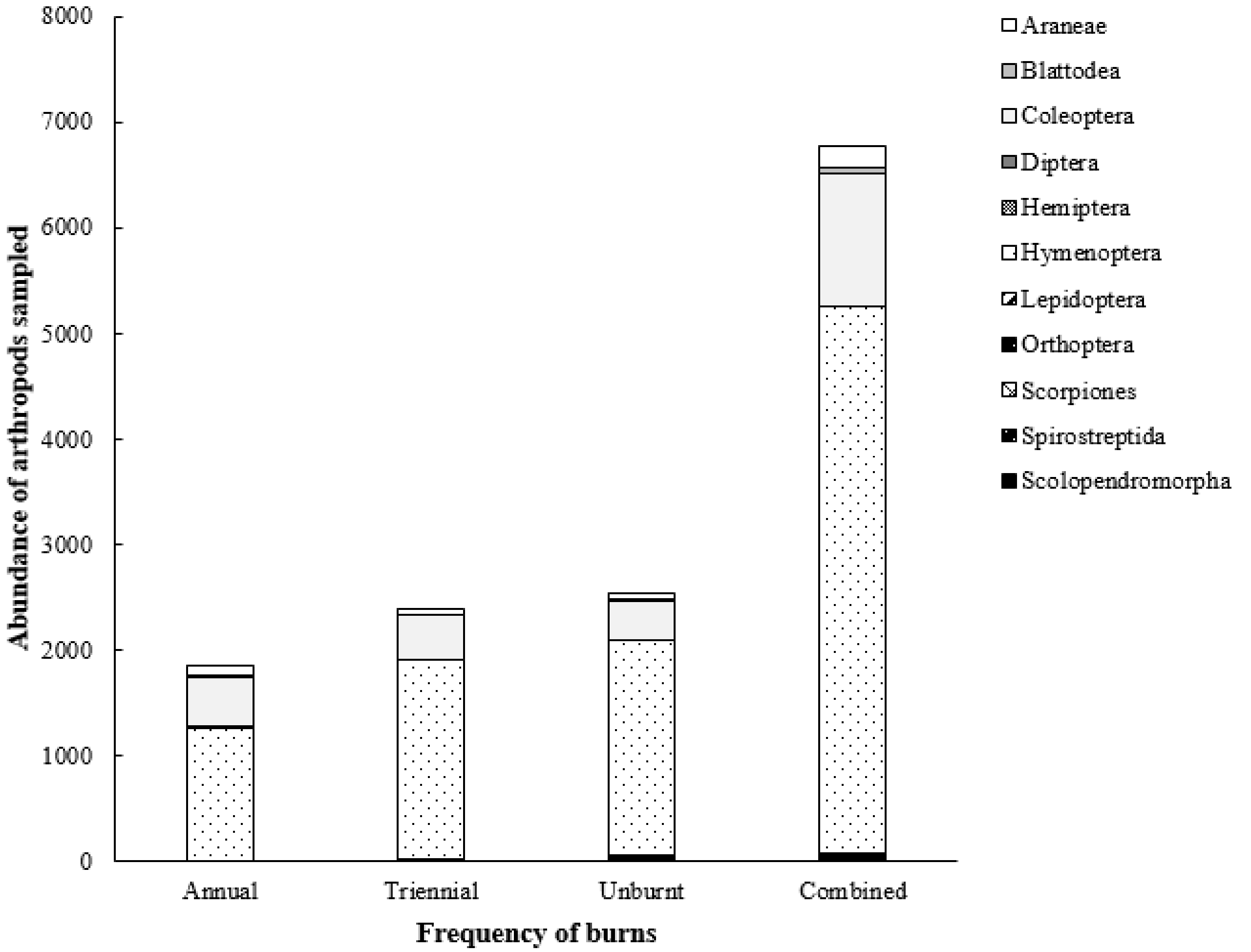

Figure 2

Abundance of arthropods sampled at the annually, triennially burnt and unburnt plots, solely and combined.

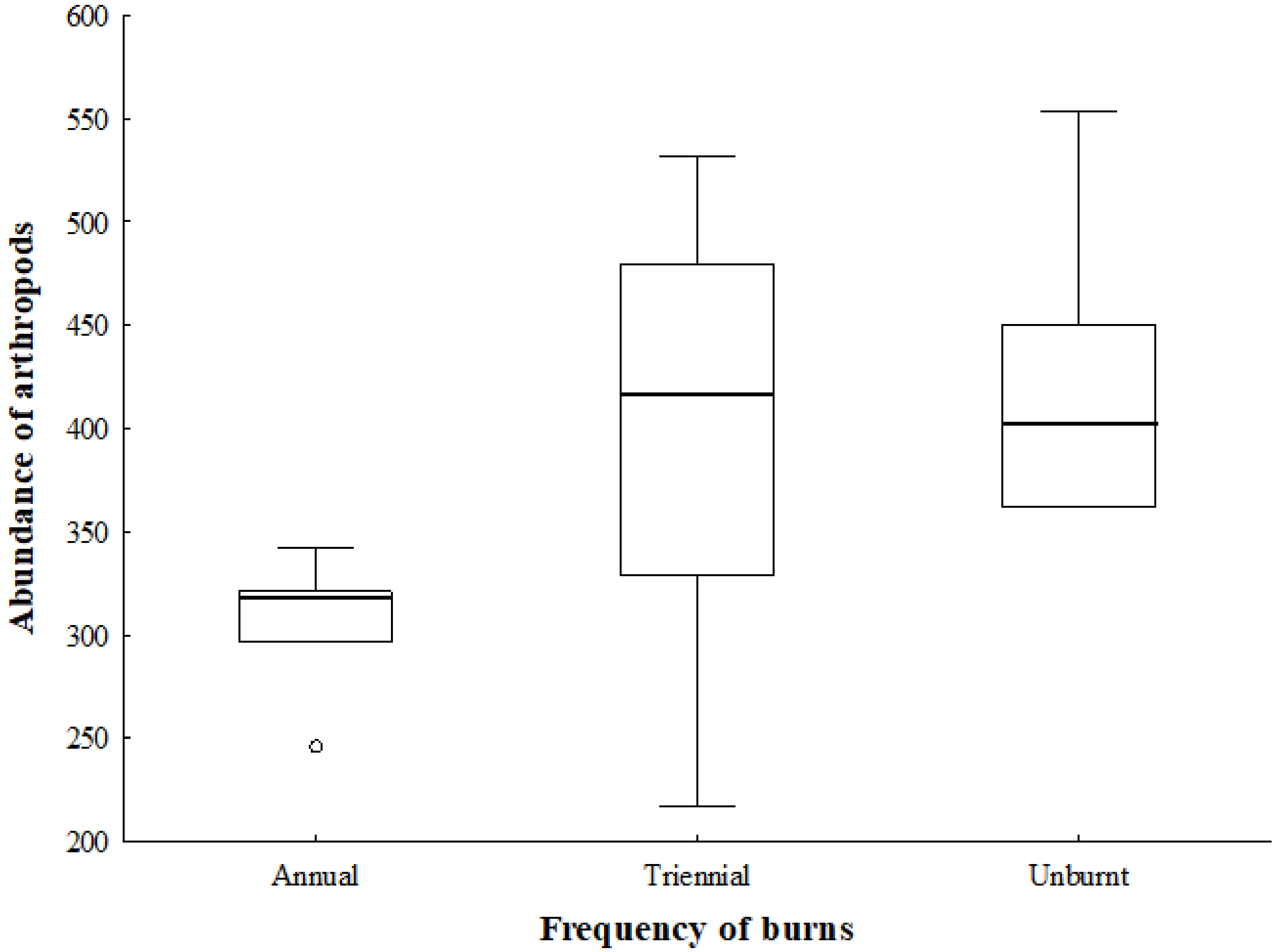

Figure 3

Boxplot showing the abundance of multi-taxon arthropods collected at the annually, triennially burnt and unburnt plots of Kruger National Park.

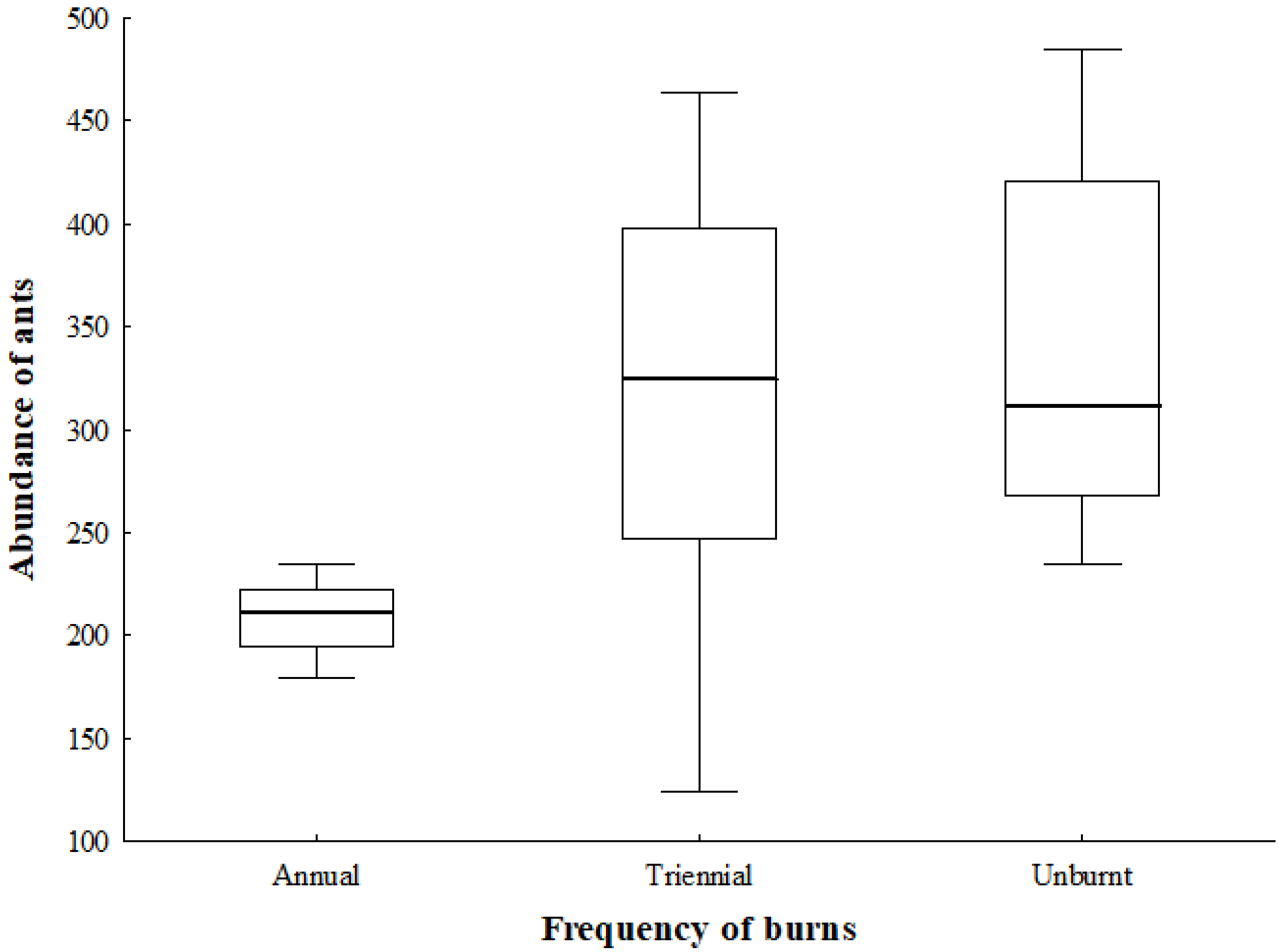

Figure 4

Boxplot showing the abundance Hymenoptera: Formicidae arthropods collected at the annually, triennially burnt and unburnt plots of Kruger National Park.

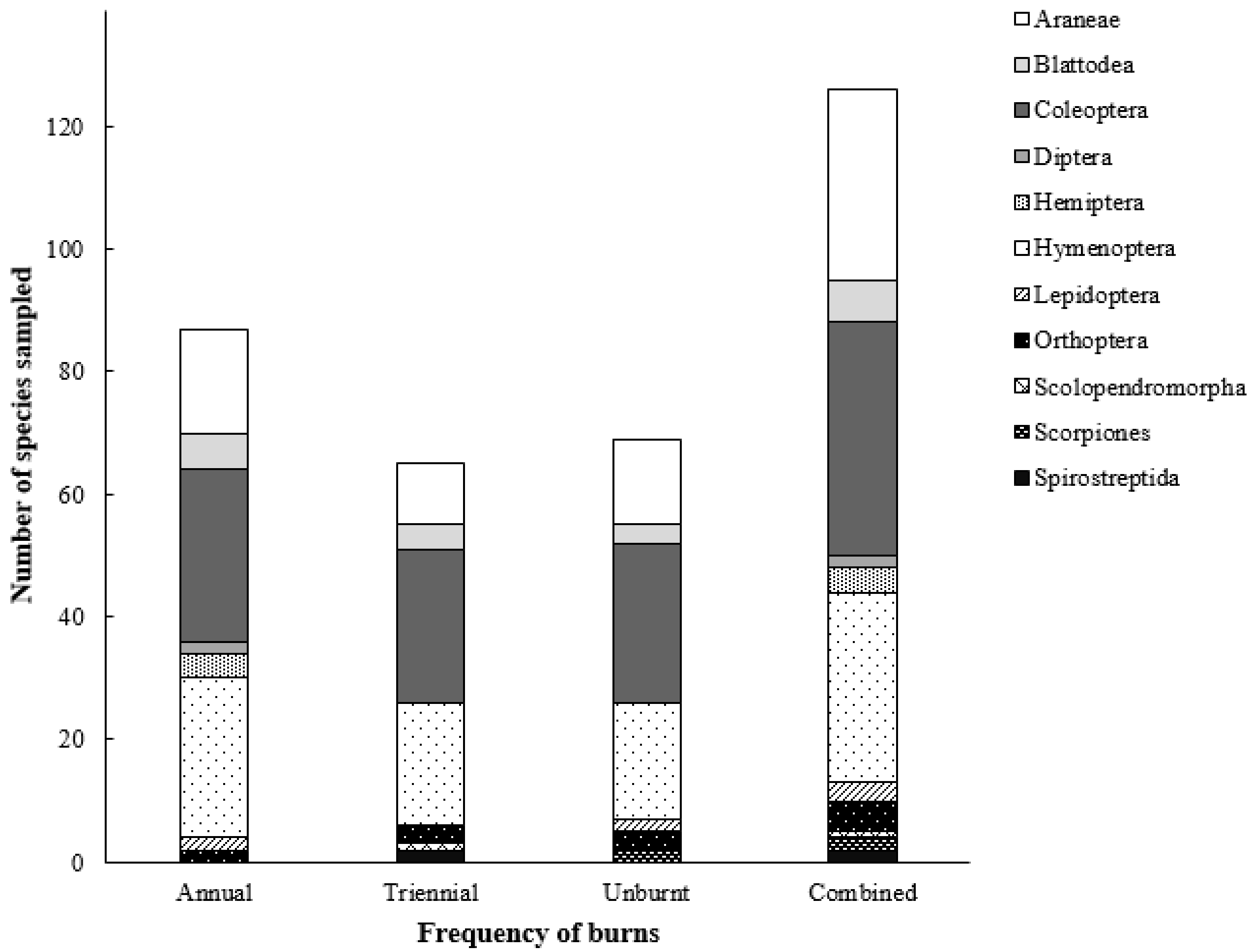

Figure 5

Number of arthropod species sampled at the annually, triennially burnt and Unburnt plots solely and combined.

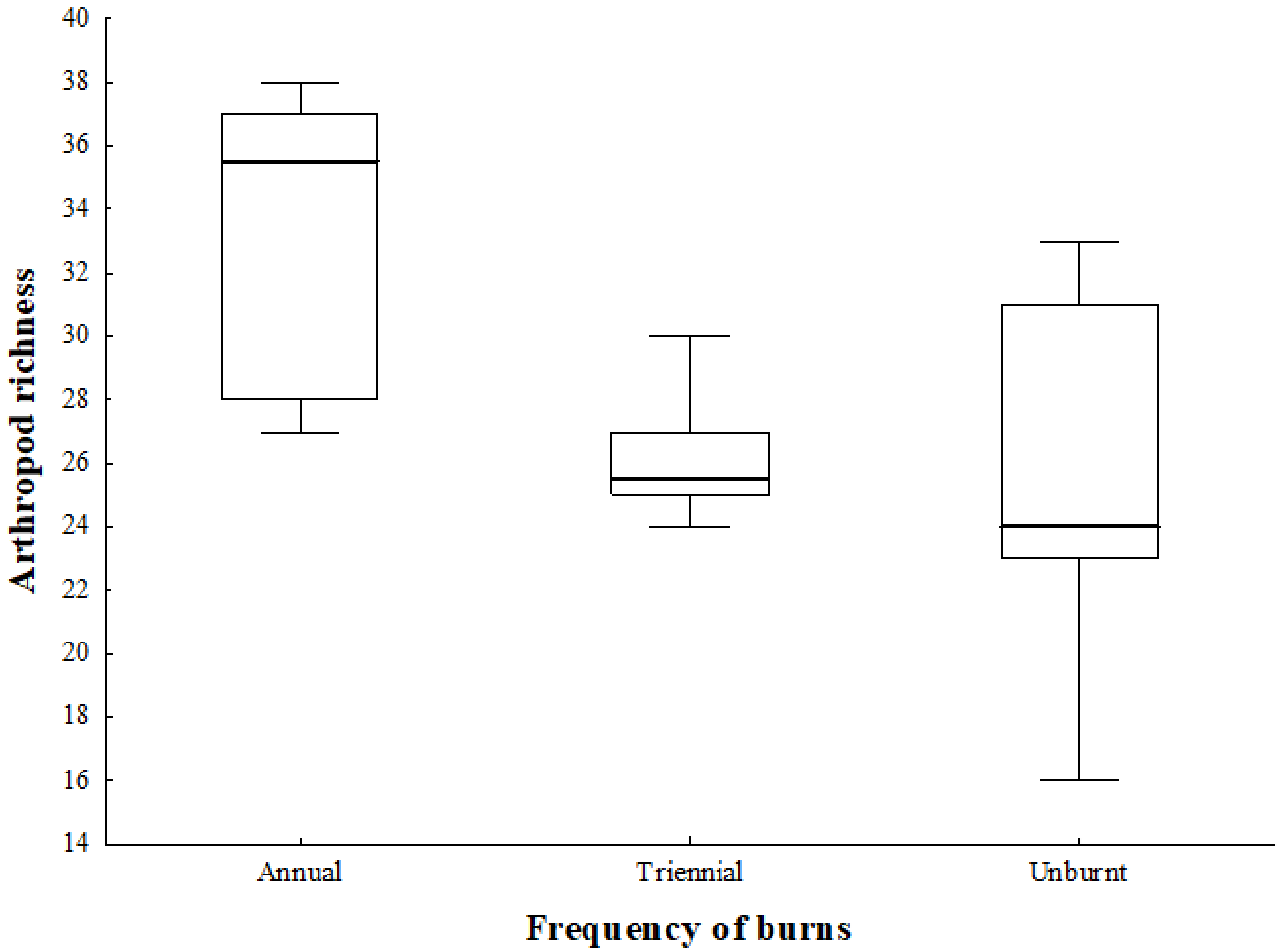

Figure 6

Boxplot showing the species richness of multi-taxon sampled at the annually, triennially burnt and unburnt plots of Kruger National Park.

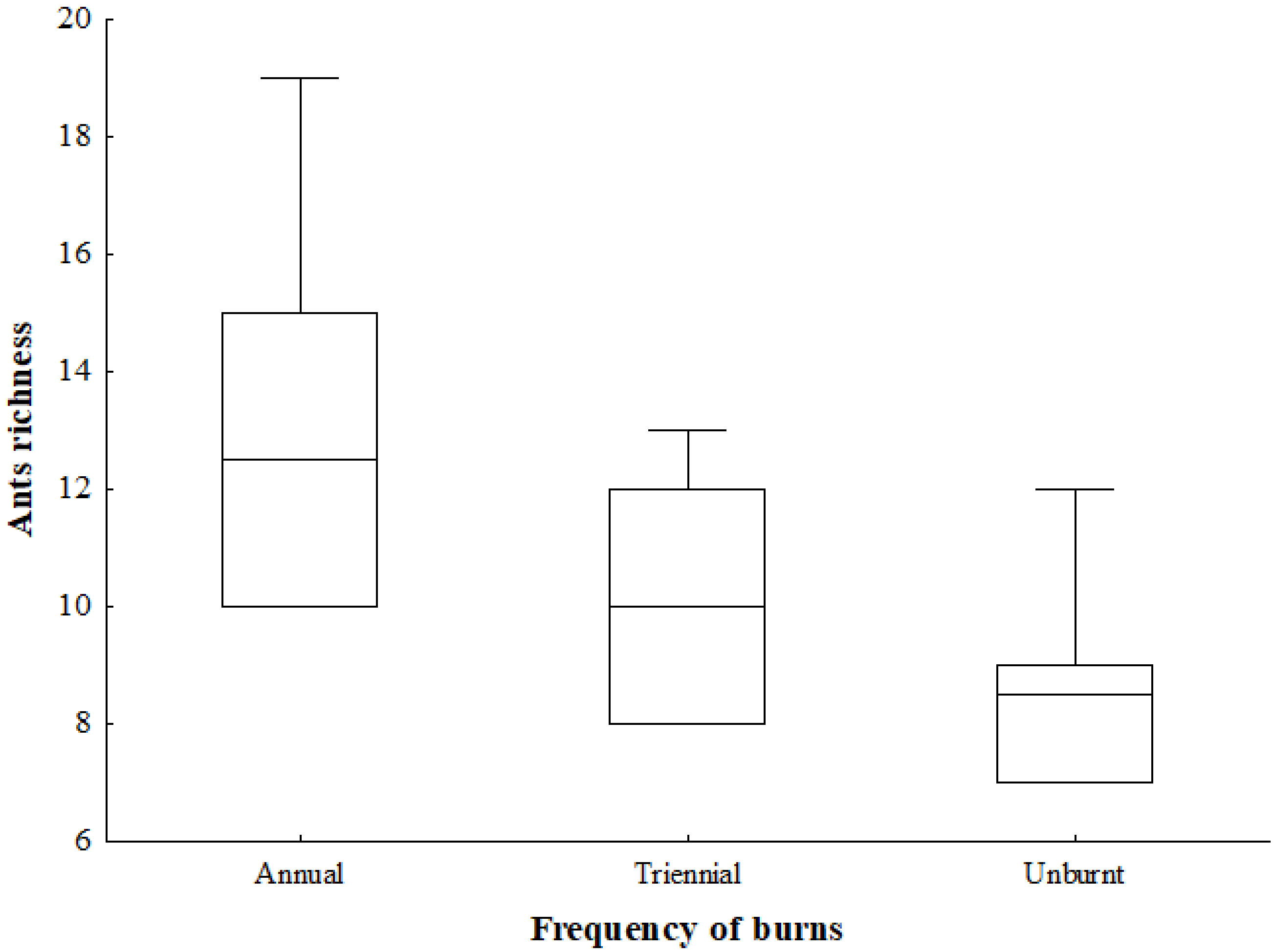

Figure 7

Boxplot showing the species richness of Hymenoptera: Formicidae sampled at the annually, triennially burnt and unburnt plots of Kruger National Park.

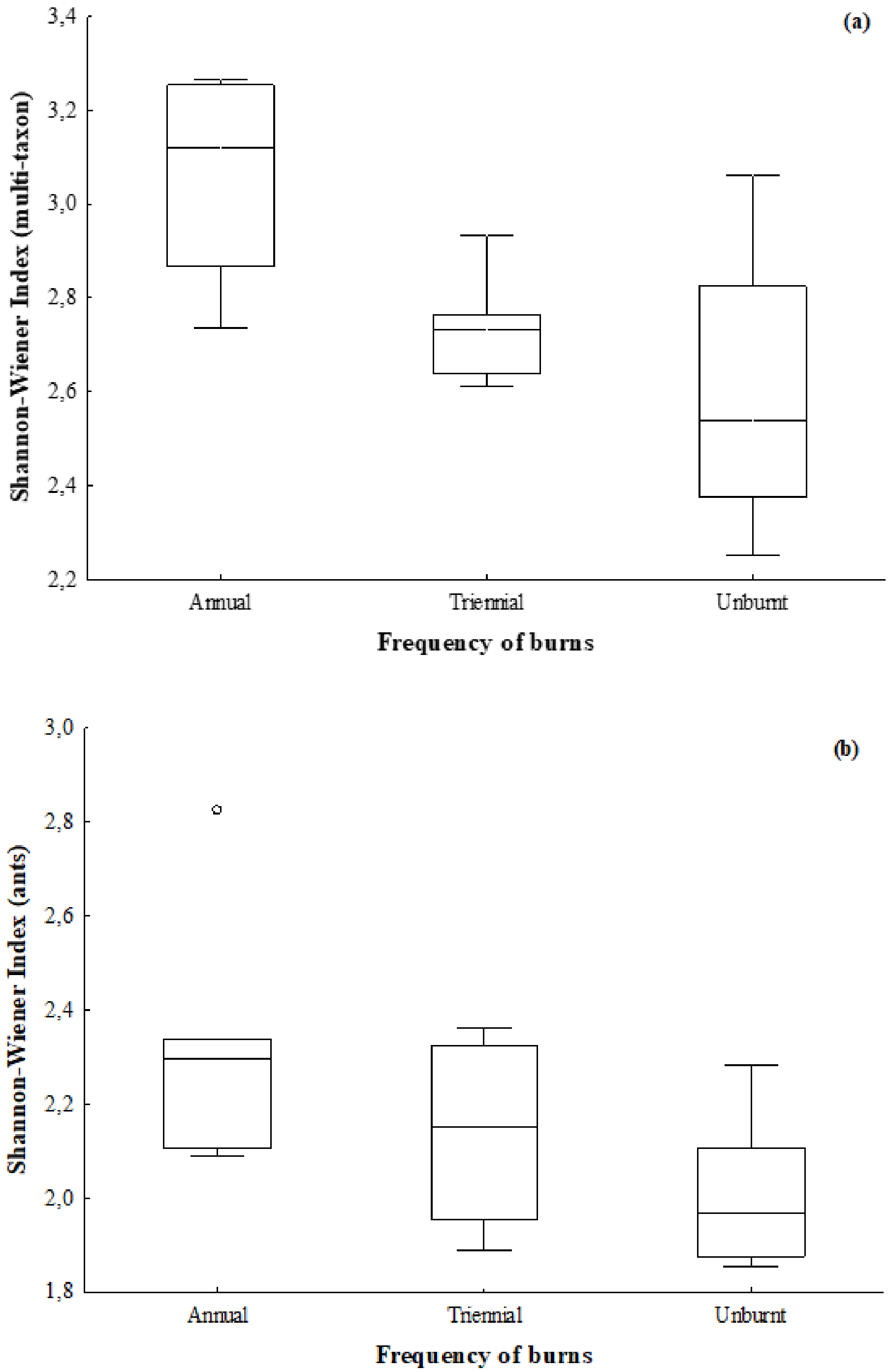

Figure 8

Boxplot showing the diversity (Shannon-Wiener diversity index) of arthropods [i.e., multi-taxon (a), and Hymenoptera: Formicidae (b)] sampled at the annually, triennially burnt and unburnt plots of Kruger National Park

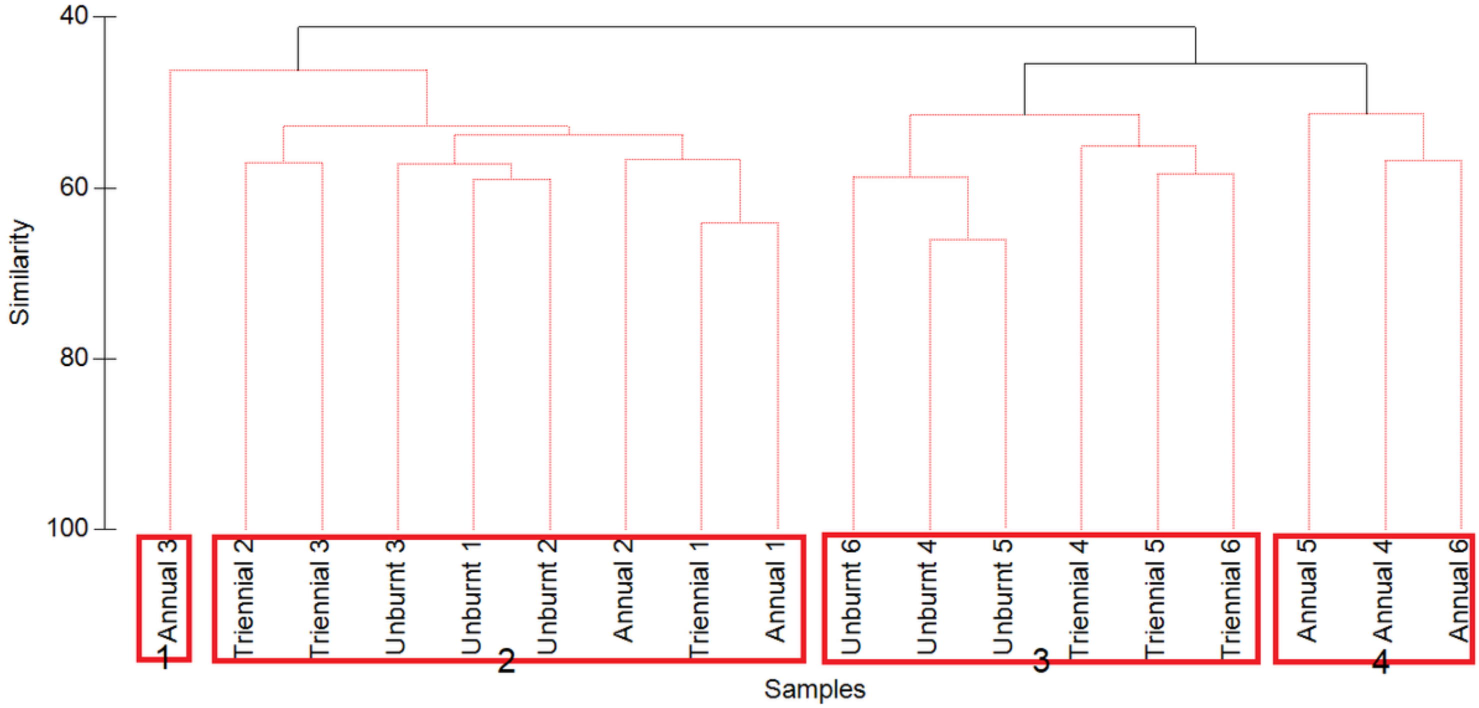

Figure 9

Classification tree showing arthropod assemblage similarities across annually, triennially burnt and unburnt plots at Kruger National Park. The group-average linking on Bray-Curtis species similarities was used to measure the similarities.

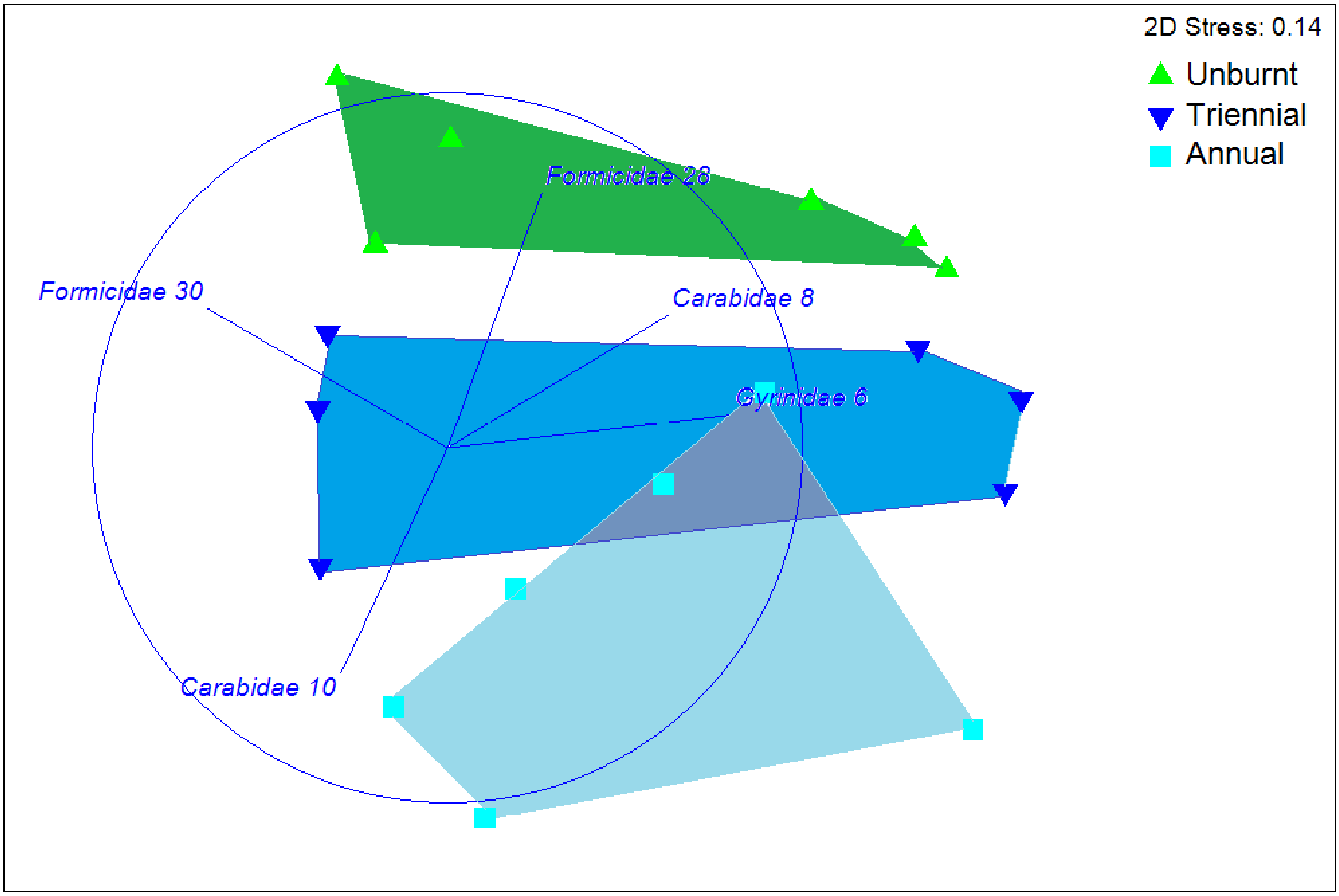

Figure 10

nMDS ordination showing the resemblance of arthropod species across annual, triennially burnt and unburnt plots surveyed at KNP. Polygons represents different plots, namely: annually burnt (light blue); triennially burnt (dark blue), and unburnt (green).