KOEDOE - African Protected Area Conservation and Science
ISSN: (Online) 2071-0771, (Print) 0075-6458

Fire and mammal herbivory on arthropods in the protected savannas: A systematic review

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Dates:
Received: 09 Oct. 2024
Accepted: 13 June 2024
Published: 22 Aug. 2025

How to cite this article:
Mukwevho, L., Ndlovu, M. & Chidawanyika, F., 2025, 'Fire and mammal herbivory on arthropods in the protected savannas: A systematic review', *Koedoe* 67(1), a1835. https://doi.org/10.4102/koedoe.v67i1.1835

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Protected areas in the savannas are key global reserves for biological diversity, including arthropods. Fire and mammal herbivory disrupts the diversity of biological organisms that alternately affects the functioning of the ecosystem. The study presents a global synthesis review of arthropod responses to varying intensities of fires and mammal herbivory in the protected savannas. We hypothesise that the intensity of predetermined fires and mammal herbivory has cascading impacts on abundance, species richness and diversity of terrestrial arthropods in the protected savannas. A minimum selection criteria was used to collate relevant literature from electronic databases of previous studies performed in the subtropical regions of Australia, Brazil and South Africa. Arthropod orders were used to group ecological indicators in 84.6%, while the functional traits were used in 15.4% of the studies. The orders included Hymenoptera (i.e. Formicidae), which was used in 81.8% of the studies selected for this systematic review, while Orthoptera, Araneae and Coleoptera were each used in 45.5%, 36.4% and 36.4% of the studies, respectively. In addition, Hemiptera and Lepidoptera were used as indicators in 27.3%, while Blattodea and Diptera were used in 18.2% of the studies. Collembola and functional groups (herbivores, omnivores and predators) were used as indicators in less than 9.1% of the studies. Fire and mammal herbivory significantly influenced the abundance and species richness of Hymenoptera, Lepidoptera, Orthoptera and multi-taxon. However, the response of arthropods (i.e. abundance and species richness) to the intensities of disturbances did not vary significantly at burnt and grazed plots.

Conservation implications: A similar response to intensities of disturbance suggests that an array of arthropod orders and functional groups (solely or combined) are indistinguishably affected by fire and mammal herbivory. Thus, arthropods could potentially be a viable ecological indicator to ascertain the magnitude of impacts. Policies encouraging the integration of different intensities of fire and mammal herbivory across protected areas should be encouraged to optimise the conservation of arthropods, including the threatened morphospecies.

Keywords: biological conservation; disturbance; ecological indicators; invertebrate assemblages; southern hemisphere.

Introduction

Savanna biomes comprise of mixed woodland and grassland ecosystems that cover approximately 20% of the earth's terrestrial surface (Scholes & Archer 1997), 46% of the southern African region and approximately 34.3% of the total land area in South Africa (Low & Rebelo 1996; Van Wilgen 2009a). Extensive fuel loads owing to high plant biomass are one typical characteristic of savanna landscapes making them highly prone to fire during the dry winter season (Friedel, Allan & Duguid 2014; Little, Hockey & Jansen 2015). Fire, therefore, influences the processes of the savanna ecosystem, such as nutrient recycling, seedling recruitment and subsequent plant biomass accumulation, all of which are responsive to different intensities of fire with cascading impacts on biological organisms within the food web (Paolucci et al. 2017; Pryke & Samways 2012; Reinhart, Dangi & Vermeire 2016).

Grazing and nipping of the vegetative and reproductive parts of the plant by either game or domestic animals and arthropods disrupt the community composition of plants and associated organisms in the ecosystem (Ebeling et al. 2018; Gebeyehu & Samways 2003; Zhu et al. 2012). Veld disruption resulting from mammal herbivory and insect herbivory reduces the population of ecological primary producers such as tree, forbes and grass species (Friedel et al. 2014; Little et al. 2015). Hence, the magnitude of plant and arthropod community shifts depends on the intensities of disturbances in the protected grassland, forests and savannas (Van Wilgen 2009a; Wardle et al. 2004).

In general, fire and mammal herbivory are among the most common management practices known as drivers of biodiversity in the grasslands, forests and savanna systems across protected areas worldwide (Borgström et al. 2016; Davis et al. 2014; Little et al. 2015; Van der Waal et al. 2011; Veen et al. 2008). Although fire and mammal herbivory (i.e. solely or combined) encourage coppicing and flushing of ecological primary producers, they interrupt the community composition of plants, vertebrates and invertebrates in the ecosystem (Eby et al. 2014; Rutina & Moe 2014; Van Klink et al. 2015). These practices yield 'top-down' pressures and drive the diversity and community composition of ecological primary producers (Castagneyrol et al. 2017; Fuhlendorf & Engle 2004; Wigley et al. 2014). The change in plant community and diversity yields direct or indirect influences on the diversity of insects and mammals at different levels within a food web (Anderson & Briske 1995; Bond & Parr 2010; Castagneyrol et al. 2017). Furthermore, fire and mammal herbivory also affect the diversity and efficiency of distinct groups of arthropods such as pollinators, coprophages and saprophages (Briones 2014; Chenchouni et al. 2015).

Fire and mammal herbivory disrupts the multitrophic interactions of the above- and below-ground organisms in protected landscapes (Schneider et al. 2016; Seibold et al. 2018; Van Dam & Heil 2011), including vertebrates and invertebrates facilitating different ecological functions in the ecosystem (Breviglieri & Romero 2017; Kehrli & Wratten 2011; Parr, Gray & Bond 2012). Top-down controls in the form of predation, parasitism and herbivory by organisms in higher trophic levels may have contrasting effects on the population of their respective hosts (Vidal & Murphy 2018; Zaugg, Benrey & Bacher 2013). Bottom-up and top-down pressures disrupt food webs and could lead to their potential collapse (Maia et al. 2019; Samways 1993; Schneider et al. 2016; Wilkinson & Sherratt 2016; Zhu et al. 2023). Immense pressures on the threatened and highly vulnerable populations of arthropods may lead to species extinction (Castagneyrol et al. 2017; Scherber et al. 2010; Vidal & Murphy 2018). Protected area managers in savanna systems around the globe thrive to ensure that there is a balance between food resources and habitats to sustain the biodiversity of ecologically important organisms (Grobler 2023; Salvatori et al. 2001; Thoresen et al. 2021; Wigley-Coetsee et al. 2022). Inevitably, the choice of a savanna management technique and the intensity at which they are employed influence the condition and functioning of an ecosystem.

Accidental fires and major shifts in the population of the significant ecological drivers such as the elephants (*Loxodonta africana*) and rhinos (i.e. *Ceratotherium simum*, *Dicerorhinus sumatrensis*, *Diceros bicornis* and *Rhinoceros unicornis*) affect the management of protected areas and ultimately influence assemblages of biodiversity and their conservation (Davis et al. 2014; Ferreira et al. 2015; Harrington, Woiwod & Sparks 1999; Van Wilgen 2009b). To document the implications of the shifts, dozens of PAs in the savanna landscapes established the long-term fire and grazing exclosures with different intensities of disturbances to succour in developing the best management plans that do not compromise the diversity of biological organisms (Titshall, O'Connor & Morris 2000; Van Wilgen 2009a; Wigley et al. 2014). Enormous efforts have been invested in monitoring biodiversity and tracking their shifts in response to fire and mammal herbivory in the protected savannas (Siemann et al. 2017; Van Wilgen 2009a); this includes South Africa as the signatory to the Convention on Biological Diversity (abbreviated as CBD, thereafter). Among commonly assessed ecological indicators in the protected savannas are the plants, invertebrates and vertebrates (Siddig et al. 2016).

In terrestrial protected ecosystems of global grasslands and savannas, impacts of fires and mammal herbivory were thoroughly documented and are known to have major impacts on the diversity of arthropods (Joshi et al. 2004; Vidal & Murphy 2018; Zaugg et al. 2013). These management techniques yield either transient or permanent changes in the abundance and composition of sensitive communities of arthropods in both regional and global scales (Davis et al. 2014; Goosey et al. 2019; Harrington et al. 1999). Because of their sensitivity to disturbances, different groups of arthropods (e.g. Araneae, Blattodea, Coleoptera, Collembola, Hymenoptera, Lepidoptera and Orthoptera) were identified as key organisms that may be used as biological indicators to ascertain the magnitude of habitat modifications resulting from climate change, invasion, fires and mammal herbivory (Danks 1992; Farrell et al. 2015; Menta & Remelli 2020; Van Klink et al. 2015). These organisms include the plant, below- and above-ground dwelling arthropods whose diversity is greatly affected by ecological disturbances (Langor & Spence 2006; Samways 1993; Uehara-Prado et al. 2010). Therefore, adequate knowledge of the diversity and sensitivity of these organisms to the varying intensities of fire and mammal herbivory will conjure the influence of the adopted management policies in the conservation of arthropods in different protected savannas. This study used available literature to assess the impact of fire and mammal herbivory on the abundance and species richness of arthropod taxa in the protected savannas.

Research methods and design

Literature search

We conducted a systematic review of all the relevant peer-reviewed articles sourced from four search engines, namely Google Scholar (https://scholar.google.com/), JStor (https://www.jstor.org/), Scopus (https://www.scopus.com) and Thomson Reuters Web of Science (https://www.webofscience.com/wos/) from June 2019 to September 2020 (i.e. updated in August 2024). Research articles were pooled to measure the responses of arthropod assemblages to different intensities of fire and mammal herbivory in protected areas (i.e. also known as nature reserves) along the savanna landscapes throughout the globe. To explore the published literature on Google

Scholar, JStor, Scopus and Web of Science, we employed a Boolean search strategy, combining search terms or phrases using AND/OR operators within the query boxes on the respective websites. The haphazardly utilised keywords on various search engines included: 'fire', 'mammal herbivory or grazing', 'veld management', 'arthropods diversity', 'arthropod assemblages', 'savanna landscape' and 'protected areas'. We therefore refined our search using the Boolean operators, 'fire' OR 'mammal herbivory' AND 'arthropod assemblages' NOT 'plants, birds or mammals', to focus on studies that assessed arthropods on burnt and grazed plots within protected areas with savanna vegetation type in South Africa and elsewhere in the world (Sexton & Emery 2020).

Selection criteria and data collection

The selection of articles for this review was conducted following a systematic approach in line with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al. 2015; Parums 2021). The search engines yielded a total of 2640 research articles (i.e. book chapters, theses and peer-reviewed research papers) that assessed the impact of fires and mammal herbivory on biological indicators such as trees, grasses, forbs, mammals and arthropods (Borgström et al. 2016; Burkepile et al. 2016; Levick, Baldeck & Asner 2015; Wigley et al. 2014) at various landscapes. This large dataset suggests the high global relevance of the topic among scholars and conservation communities in general. Following the removal of research articles because of their incongruency with the defined scope of focus, a total of 160 articles were found to be eligible for further screening. Thus, 2480 research articles were discarded because of their irrelevance or incongruency with the defined scope of focus. Research reviews and scientific article that documented the response of non-targeted ecological indicators (trees, forbs, grasses, mammals) were excluded. Furthermore, studies that assessed a distinctive group of ecological indicators known as arthropods (e.g. either solely or combined) to ascertain the impact of varying intensities of fire and mammal herbivory in forests, grasslands, shrublands ecosystems or unprotected savannas were omitted for this review. Of the screened research articles, 98 were further assessed for eligibility while 62 were omitted as a result of duplication. Apart from the duplication of research articles across different search engines, published scientific reports and thesis chapters were reproduced as peer-reviewed scientific articles (Figure 1).

Of the eligible studies, 86 peer-reviewed articles were excluded because of the use of disturbance intensities and field manipulation techniques that did not coincide with the baseline requirements for the current systematic review. Ambiguity in the treatments and study design resulted in the disqualification of such peer-reviewed scientific articles. For example, studies that assessed the arthropod diversities following post-accidental or once-off prescribed fires (Ferrenberg et al. 2006; Haddad et al. 2015; Lavigne & Lockwood 1989) and those involving the use of mechanical techniques such as manual clearing of vegetation to simulate mammal herbivory (Cizek et al. 2012; Parker et al. 2023) were excluded. Furthermore, this review excluded studies that assessed arthropod diversity in the protected savannas where domestic grazers (e.g. cattle and sheep), either alone or in combination with game herbivores were used (Ferreira, Le Roex & Greaver 2019; Gebeyehu & Samways 2003; Goosey et al. 2019; Wilkerson, Roche & Young 2013; Wilkinson & Sherratt 2016). Studies on the response of arthropods to three grazing treatments at the Kenyan Long-term Exclosure Experiment (KLEE) were omitted from this systematic review because of the inadequacy of distinctive explanation in the intensity of grazing by herbivores (e.g. domestic, game and combined) on the grazing exclosures (Warui et al. 2005; Wilkerson et al. 2013). Fundamentally, studies that documented the temporal response or recovery of arthropods to fires or intensive mammal herbivory were excluded (Calcaterra et al. 2014; Jerrentrup et al. 2014; Yekwayo et al. 2018; Zhu et al. 2020). Lastly, we excluded studies that reported the differences in arthropod responses to two treatments only (i.e. such as 'treatment and control') rather than intensities of fire or mammal herbivory (Figure 1). Although a pool of studies assessed the influence of fire and mammal herbivory on arthropods assemblages, one or few attributes not coinciding with the baseline requirement(s) of the systematic review resulted in the disqualification of some studies.

Experiments conducted in the long-term exclosures, where no boundaries were erected to encourage heavy grazing by mega- and meso-herbivore (e.g. hereafter referred to as heavily grazed), boundaries were erected to exclude mega-herbivores only in the minimally grazed and all

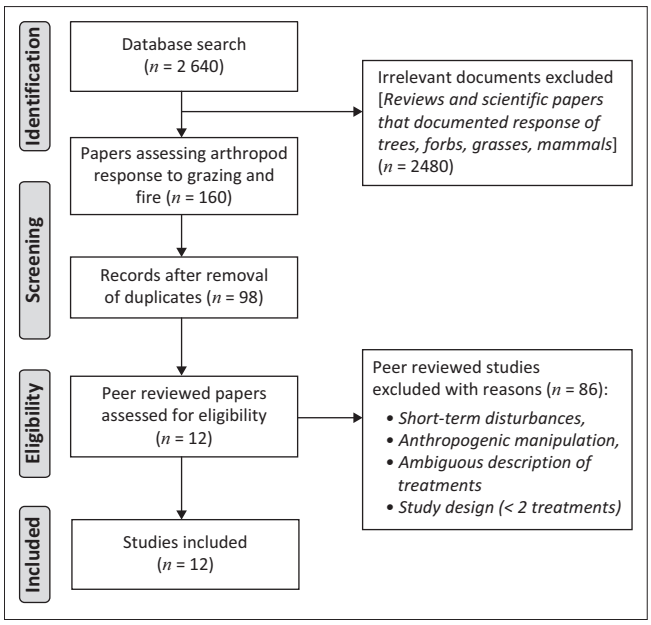

FIGURE 1: Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) flow diagram outlining study inclusion.

grazers (e.g. mega- or meso-herbivores) in the ungrazed areas were included in this study. Alternatively, experimental burnt plots, where intentional burns were carried out annually, biennially, triennially, quadrennially or quinquennially (i.e. a minimum of three treatments), were considered for this systematic review (Biggs et al. 2003; Van Wilgen 2009a). The continent or country in which the assessments were conducted was recorded. The techniques used to collect the arthropods and the collection periods were noticed.

The systematic review considered articles that compared the abundance, species richness and diversity in the periodically burnt plots and grazed exclosures of the protected savanna ecosystems. Data in the response of arthropods to fire (e.g. unburnt, annually, biennially, triennially, quadrennially or quinquennially burnt plots) and mammal herbivory (e.g. ungrazed, minimally and heavily grazed) were gathered from the text, tables and/or figures of each study included in this review. For each experiment, the influence of fire and mammal herbivory on the abundance, species richness, diversity and community composition of arthropods was documented. Taxon-specific, multi-taxon and functional group responses to intensities fire and mammal herbivory were recorded to ascertain the sensitivity of taxonomic groups to disturbances. Emulating from Wang and Tang (2019), the means, standard errors or deviations and sample sizes were extracted from the text, tables or digitised graphs. To extract the means and standard errors or deviations from the digitised graphs, GetData Graph Digitizer (version 2.26, https://getdata-graph-digitizer.software.informer.com/) was used.

Statistical analyses

All statistical analyses were performed using the software IBM SPSS Statistics, SPSS Inc., version 26. Normal quantile plots were used to verify the normality in the distribution of the data. The abundance and species richness of different ecological indicators at the fire and grazed plots conform to a normal distribution. Data for the arthropod order(s) or functional group(s) that were used as indicators in a single study were omitted during statistical analysis because of a lack of variance. To assess the influence of fire and mammal herbivory on the abundance and species richness of arthropod groups, a two-way analysis of variance (ANOVA) was used. Two-way ANOVA was followed by the pairwise tests to measure the statistical differences in the abundance and species richness among groups of arthropods (i.e. orders) and intensities of disturbances in the protected areas.

Ethical considerations

Ethical clearance to conduct this study was obtained from the University of the Free State, Interfaculty Animal Research Ethics Committee in the Zoology and Entomology Department (Bloemfontein Campus) (No. UFS-AED2018/0078).

Results and Discussion

Studies that were included in this review were conducted in the tropical and subtropical regions of Oceania, South America and Africa, respectively (Figure 2). Although recorded studies were conducted in different ecozones,

FIGURE 2: Global overview of countries that reported on the response of arthropods to different regimes of fire and mammal herbivory on the protected savanna ecosystems. Studies for both fire and mammal herbivory were recorded on countries shaded in black, whereas the countries where only the impact of fire was measured were diced.

study regions were along the savanna landscapes (Figure 2). Of these studies, 61.5% reported on the long-term impact of fire, 23.1% reported on the impact of mammal herbivory, while 15.4% reported the combined impacts of fire and mammal herbivory on arthropod assemblage and diversity at the protected savannas (Figure 3; Table 1). Of the studies that assessed the impact of fires on arthropod assemblage and diversity, 50% were conducted in Brazil, while 37.5% and 12.5% were conducted in South Africa and Australia, respectively. All studies that reported the intensities of herbivory in the long-term experimental exclosure were conducted in the protected areas of South Africa, namely the Kruger National Park (67%) and Hluhluwe iMfolozi National Park (33%). Lastly, studies on the combined impact of fire and mammal herbivory were conducted at Kruger National Park, South Africa (Figure 4; Table 1).

The results demonstrated that the response of arthropods to intensities of fire and mammal herbivory was conducted in limited regions resonate with those presented in a review by González-Megías, Gómez and Sánchez-Piñero (2004), Nghiyalwa et al. (2021) and Oikonomou et al. (2023), which included studies from three continents. Therefore, trivial documentation on the long-term

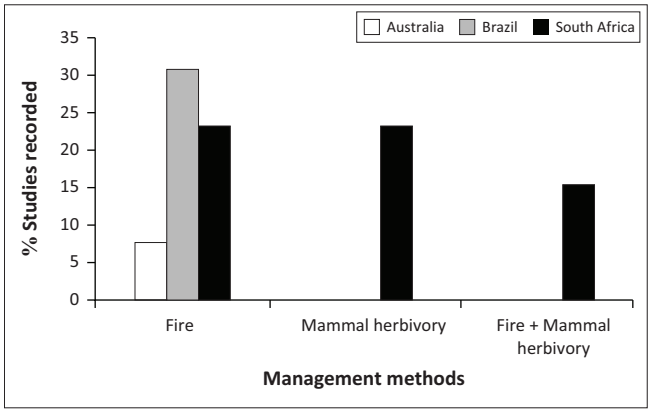

FIGURE 3: Percentage of peer-reviewed studies that documented the impact of fire and mammal herbivory (solely or combined) on arthropods in Australia, Brazil, and South Africa.

TABLE 1: Studies that evaluated the effects of fire and mammal herbivory on different orders and functional groups of arthropods at the protected areas (PAs) throughout the global savanna ecosystems.

Country or Nature reserve	Site and year established	Year of the transect/ EBP establishment	Year of data collection	Savanna management	Treatments	Sampling technique(s)	Sampling period (days)	Target species	Reference(s)
1. South Africa									
Hluhluwe-iMfolozi	Mfolozi	2000	2010	Herbivore grazing	U, P and H	Sweep net	2	Orthoptera	Van der Plas & Olff 2014
Kruger National Park	Nkuhlu	2002	2008	Herbivore grazing	U, P and H	Pitfall and sweep net	4	Araneae, Coleoptera, Hymenoptera, Orthoptera and multi-taxons	Bell 2009; Jonsson et al. 2010
	Letaba and Nkuhlu	2002	2019	Herbivore grazing	U, P and H	Pitfall and active searches	5	Araneae, Blattodea, Coleoptera, Diptera, Hemiptera, Hymenoptera, Lepidoptera and Orthoptera	Mukwevho et al. 2023
	Mopane, Satara and Pretoriouskop	1954	2000 and 2002	Fire frequency	C, A, B and T	Pitfall	5	Hymenoptera	Parr et al. 2004
	Pretoriuskop	1954	2009, 2010 and 2012	Fire frequency	C, A and T	Pollard walk transect method	1	Lepidoptera	Gaget et al. 2020
	Tsende and Skukuza	1954	2019	Fire frequency	C, A and T	Pitfall and active searches	5	Araneae, Blattodea, Coleoptera, Diptera, Hemiptera, Hymenoptera, Lepidoptera, Orthoptera, Scolopendromorpha, Scorpiones, Spirostreptida and Multi-taxon	Mukwevho et al. 2024
	Letaba and Nkuhlu	2002		Fire and mammal herbivory	G, F (Q), F+G and Undisturbed	Tullgren funnels	7	Detritivores, Fungivores, Herbivores, Omnivores and Predator	Thoresen et al 2021
	Tsende and Skukuza (EBPs); Letaba and Nkuhlu (exclosures)	1954; 2002	2019	Fire and mammal herbivory	C, A and T; U, P and H	Pitfall and active searches	5	Detritivores, granivores, haematophagous, herbivores, nectarivores, omnivores, predators and scavengers	Mukwevho et al. 2025
2. Brazil									
Mato Grosso	Fazenda Tanguro	2004	2013	Fire frequency	C, A and T	Pitfall	2	Hymenoptera	Paolucci et al. 2017
Sumidouro State Park	Minas Gerais State		2012	Fire frequency	C, 1m, A and B	Pitfall	4	Hymenoptera	de Oliveira Canedo-Júnior et al. 2016
Cerrado reserve	Parque Nacional das Emas	1994	2006	Fire frequency	C, A and T	Pitfall	5	Araneae, Coleoptera, Collembola, Hemiptera, Hymenoptera and Orthoptera	Uehara-Prado et al. 2010
Reserva Ecológica do IBGE	Projeto Fogo	1991	2011	Fire frequency	C, B and Q	Pitfall	2	Hymenoptera	Maravalhas and Vasconcelos 2014
3. Australia									
Kakadu National Park	Munmarlar	1972	1986	Fire frequency	C, A and B	Pitfall	2	Hymenoptera	Andersen 1991

Note: Please see the full reference list of the article, Mukwevho, L., Ndlovu, M. & Chidawanyika, F., 2025, 'Fire and mammal herbivory on arthropods at the protected savannas: A systematic review', *Koedoe* 67(1), a1835. https://doi.org/10.4102/koedoe.v67i1.1835

EBP, experimental burnt plot; U, ungrazed; P, partly grazed; H, highly grazed; C, unburnt; 1m, 1 month; A, annual; B, biennial; T, triennial; Q, quadrennial; G, grazed; F, Fire.

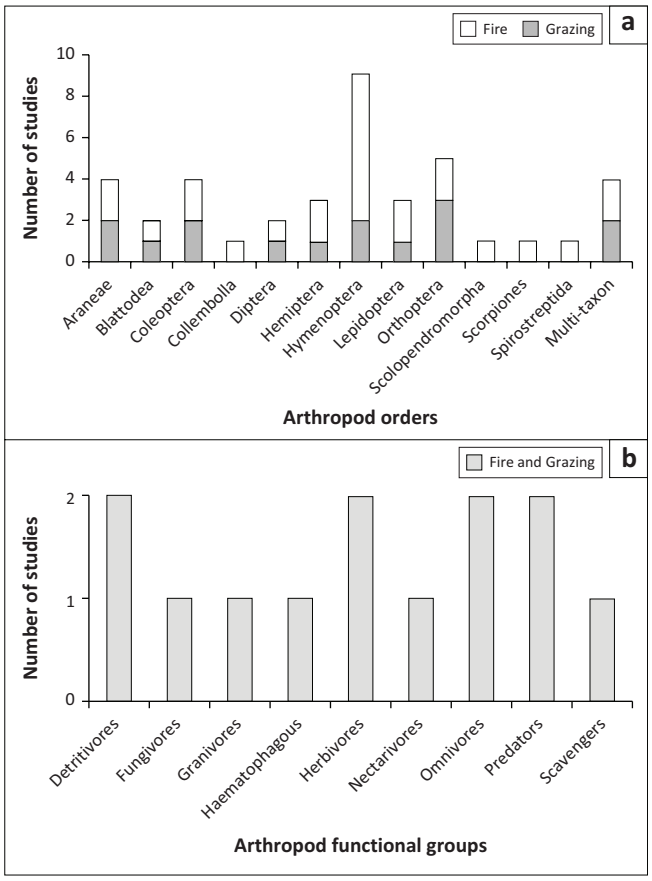

FIGURE 4: The number of studies that assessed the different orders. (a) Functional groups; and (b) Arthropods to ascertain the long-term impacts of fire and mammal herbivory in protected savannas.

response of arthropods to the intensities of fires and mammal herbivory could be associated with the economics (e.g. a lack of adequate funding to erect infrastructures, remunerate specialists or field assistants, transport and purchase other consumables) of maintaining the fire plots and grazing exclosures and conservation needs of each region (Biggs et al. 2003; Pekor et al. 2019; Penman et al. 2020). The dominance of studies assessing the post-effects of accidental fires and temporal grazing compared to those assessing the long-term effects is inevitable (Bieber et al. 2023; Moretti, Obrist & Duelli 2004). Studies outlined costs associated with fencing of exclosures and protected areas to control access as a major factor compromising access to protected areas and experimental plots while jeopardising the integrity of conservancy and ongoing experiments (Linden et al. 2023). Humans and megaherbivores pose direct damage to erected fences and parks incur high costs during follow-up repairs and reconstruction to ensure restricted access (Cabral de Mel et al. 2023; Pekor et al. 2019; Wilkinson et al. 2021). Furthermore, accidental fires may jeopardise the management plan of the experimental burnt plots in the protected savanna ecosystems, where firebreaks are not consistently maintained (Biggs et al. 2003; Scholtz et al. 2022).

Among the groups of arthropods assessed as ecological indicators were Araneae, Blattodea, Coleoptera, Collembola, Diptera, Hemiptera, Hymenoptera, Lepidoptera and Orthoptera. Of the studies documented, 63.6% assessed one focal order of arthropods as an ecological indicator, while 36.4% assessed more than four orders of arthropods to ascertain the impacts of fire or mammal herbivory in the protected areas (Figure 3). Furthermore, two studies assessed the response of functional groups of arthropods (i.e. Detritivores, Fungivores, Granivores, Herbivores, Nectarivores, Omnivores, Predator and Scavengers) as ecological indicators to ascertain the impact of fire and mammal herbivory in the protected area of Kruger National Park, South Africa (Mukwevho et al. 2025; Thoresen et al. 2021). A group of arthropods, namely Hymenoptera (i.e. Formicidae), was assessed as an ecological indicator in 81.8% of the studies recorded. Other extensively studied orders of arthropods include Orthoptera, Araneae, Coleopterans and Hemiptera and Lepidoptera with 45.5%, 36.4%, 36.4%, 27.3% and 27.3%, respectively, used as ecological indicators in fire and grazed experiments. The remaining orders of arthropods, namely Blattodea, Collembola and Diptera were used as ecological indicators in 9.1% – 18.2% of the studies recorded. Lastly, 66.7% of the studies that assessed the effect of mammal herbivory on arthropods monitored the response of multi-taxon, while only 25% of the studies assessed more than one order of arthropods to ascertain the impact of fire regimes (Figure 4; Table 1).

The broad use of the Hymenoptera (i.e. Formicidae or ants) as ecological indicators in dozens of studies included in this review manifests its global importance as a widely distributed focal group that is extremely sensitive to ecological disturbances in the forests, savannas and grasslands (Andersen 2019; Hoffmann 2010; Parr & Bishop 2022; Ribas et al. 2012). The wide use of Hymenoptera as an ecological indicator compared to Coleoptera, Araneae and other focal orders was contrary to the patterns reported by Solascasas, Azcárate and Hevia (2022), which demonstrated that beetles were the commonly assessed ecological indicators in the temperate grasslands with up to 49% of the studies reporting on the response of this focal order to disturbances. Although studies assessing the impact of fires and mammal herbivory on functional groups of arthropods are minimal, the use of multi-taxon by a considerable number of studies in the savanna ecosystems presents the robustness of results reported in these ecosystems (Samways, McGeoch & New 2010). Thus, the inclusion of all arthropods (i.e. regardless of their orders or functional groups) provides a comprehensive representation of their response to anthropogenic disturbances, fires and mammal herbivory.

This study reported the impacts of fire and mammal herbivory on the abundance, biomass, species richness, diversity and assemblage composition of arthropods in the protected savanna and grassland ecosystems. All studies that measured the intensity of mammal herbivory on arthropods assessed the abundance and species richness of different focal groups. Of the studies that measured the

impact of fires, a total of 75% assessed the abundance, 62.5% assessed the species richness and 25% assessed the diversity of arthropods. Lastly, a single study assessed the abundance, species richness and biomass of different functional groups of arthropods in a protected area where fire was integrated with mammal herbivory (Figure 4). The use of the matrices such as the abundance, biomass, species richness and diversity was not unique to this study but was used in multiple systematic reviews to ascertain the impact of anthropogenic activities and landscape management in the grasslands, savannas, forests and agroecosystems (Reis et al. 2024; Wang & Tang 2019).

Studies showed that the abundance of arthropods significantly varied among orders at the burnt ($F_{3, 32} = 3.722$, $P < 0.001$) and grazed ($F_{4, 108} = 6.637$, $P < 0.001$) plots with the highest numbers recorded from the Hymenoptera compared to Araneae, Coleoptera, Collembola, Hemiptera and Orthoptera. Although the abundance of arthropods did not statistically vary among the intensities of fires ($F_{2, 32} = 1.990$, $P < 0.148$), and mammal herbivory ($F_{2, 108} = 1.082$, $P < 0.343$), numbers were higher at the undisturbed (i.e. unburnt, and ungrazed) compared to those recorded in the burnt or grazed plots. Lastly, the abundance of arthropods was not significantly influenced by the interaction between arthropod orders and intensity of disturbances at the burnt ($F_{6, 32} = 0.076$, $P = 1.000$) and grazed ($F_{8, 108} = 0.273$, $P = 0.973$) plots. For both fire and grazed experiments, the abundance of Hymenoptera varied compared to other orders of arthropods. While Orthoptera and Lepidoptera showed positive response to fires, only multi-taxon responded to mammal herbivory (Table 2). The uniformity in the response by different orders of arthropods used as bioindicators ascertains the resilience of unique groups to fires and mammal herbivory. Several reviews and research article reported the resilience of different groups of arthropods (e.g. Araneae, Coleoptera, Hymenoptera, Orthoptera and multi-taxon) to ecological disturbances in the protected areas (Anderson et al. 2011; Spiller et al. 2018; Yekwayo et al. 2018; Zhu et al. 2020). Arthropods with sterling dispersal abilities (i.e. Lepidoptera and Orthoptera) or those with underground nests (i.e. Hymenoptera) endure fire or mammal herbivory. Although a subset of the insect community inhabiting the ecosystem during burning or life stages that may be indulged together with plant materials during mammal herbivory, influx and continual reproduction may result in the accelerated recovery of such species. Irrespective of the beneficial implications of fires and mammal herbivory in the vegetation community and condition, the management techniques yield direct impacts (i.e. killing of individual arthropods) in the abundance of arthropods, especially the less mobile immatured and adults inhabiting the vegetation in the savanna landscapes (Van Noordwijk et al. 2012).

The species richness of arthropod focal orders was significantly influenced by mammal herbivory ($F_{4, 108} = 5.665$, $P < 0.001$) but not by the intensities of fires ($F_{5, 37} = 1.983$, $P = 0.136$) in the protected savannas. Results also showed that the response of different focal orders did not significantly vary among intensities of disturbances at the Experimental Burnt Plots (EBPs) ($F_{5, 37} = 2.113$, $P = 0.117$) and grazed exclosures ($F_{2, 37} = 11.107$, $P = 0.400$). Lastly, the species richness of arthropods was not significantly influenced by the interaction between arthropod orders and intensities of disturbances in the EBPs ($F_{10, 37} = 1.429$, $P = 0.244$) and grazed ($F_{8, 108} = 11.646$, $P = 0.464$) treatments.

TABLE 2: Pairwise results showing statistical differences in the abundance among orders of arthropods collected at the experimental burnt and grazed plots in the protected savannas.

Management technique	(I) Group 1	(J) Group 2	Mean difference (I-J)	s.e.	*p*-values	95% CI for difference	
						Lower bound	Upper bound
Fire	Araneae	Coleoptera	-29.322	77.072	0.706	-185.951	127.307
		Hymenoptera	-131.73	65.17	0.051	-264.172	0.712
		Lepidoptera	-200.161	94.393	**0.041**	-391.992	-8.331
		Orthoptera	1.447	77.072	0.985	-155.182	158.076
	Coleoptera	Hymenoptera	-102.408	65.17	0.125	-234.85	30.034
		Lepidoptera	-170.839	94.393	0.079	-362.669	20.992
		Orthoptera	30.769	77.072	0.692	-125.859	187.398
	Hymenoptera	Lepidoptera	-68.431	84.954	0.426	-241.078	104.216
		Orthoptera	133.177	65.17	**0.049**	0.736	265.619
	Lepidoptera	Orthoptera	201.608	94.393	**0.04**	9.778	393.439
Grazed	Araneae	Coleoptera	-3.651	11.717	0.756	-26.894	19.593
		Hymenoptera	-53.937	13.739	**< 0.001**	-81.193	-26.682
		Orthoptera	-3.466	11.345	0.761	-25.972	19.039
		Multi–taxon	-33.027	10.803	**0.003**	-54.457	-11.598
	Coleoptera	Hymenoptera	-50.287	13.739	**< 0.001**	-77.542	-23.031
		Orthoptera	0.184	11.345	0.987	-22.321	22.69
		Multi–taxon	-29.377	10.803	**0.008**	-50.806	-7.947
	Hymenoptera	Orthoptera	50.471	13.424	**< 0.001**	23.842	77.099
		Multi–taxon	20.91	12.968	0.11	-4.816	46.636
	Orthoptera	Multi–taxon	-29.561	10.398	**0.005**	-50.187	-8.934

Note: The bolded *p*-values present the statistical significance in the abundance of arthropods in different orders at $P < 0.05$.
CI, confidence interval; s.e., standard error.

This study demonstrated that the response of arthropod species was not significantly different among focal orders at the burnt and grazed plots, but the response of multi-taxon was significantly different compared to individual groups (Table 3). However, the response of multi-taxon to the intensity of disturbances was analogous to that of individual focal groups at the EBPs and grazed plots. The results demonstrate that the species richness of different focal orders (i.e. Araneae, Coleoptera, Hymenoptera, Orthoptera and Lepidoptera) were equally sensitive to fires and mammal herbivory.

The sensitivity of these focal groups shows that different groups of arthropods could be successfully used as ecological indicators to ascertain the impact of fire and mammal herbivory. Furthermore, using multi-taxon improved the species representation at the burnt and grazed plots. Results reported in this study contradict those of Calcaterra et al. (2014), who reported that the broadly researched focal group of ants is among the biological indicators that may not be solely relied on because of their prompt recovery rate at approximately 6 months after fires (Andersen 1997; Andersen & Majer 2004; Andersen & Muller 2000; Peck, McQuaid & Campbell 1998; Tiede et al. 2017). The results reflect a similar recovery pattern among arthropod focal groups sampled at the protected savanna, which demonstrates the significant impact of fire and mammal herbivory at the protected savannas. Thus, implementation of integrated approaches at the protected reserves not only encourages the persistence of resilient morphospecies but also sustains the population of threatened and rare species in the natural ecosystem. Therefore, an integrated approach sustains the population of arthropods within food webs and those facilitating ecologically important functions such as pollination and decomposition (Durigan et al. 2020; Kemp & Ellis 2017). The integrated management approaches at demarcated sections of the protected areas may have far-reaching effects on the community structure and assemblages of arthropod in the savanna ecosystems.

TABLE 3: Pairwise results showing statistical differences in the species richness among orders of arthropods collected at the experimental burnt and grazed plots, which were undisturbed, minimally and heavily disturbed in the protected areas.

(I) Orders_1	(J) Orders_1	Mean difference (I-J)	s.e.	*p*-values	95% CI for difference	
					Lower bound	Upper bound
Araneae	Coleoptera	1.23	1.069	0.253	-0.892	3.353
	Hymenoptera	0.049	1.253	0.969	-2.44	2.538
	Orthoptera	0.564	1.035	0.587	-1.491	2.619
	Multi-taxon	-2.904	0.985	**0.004**	-4.861	-0.947
Coleoptera	Hymenoptera	-1.181	1.253	0.348	-3.67	1.308
	Orthoptera	-0.666	1.035	0.521	-2.721	1.389
	Multi-taxon	-4.134	0.985	**< 0.001**	-6.091	-2.177
Hymenoptera	Orthoptera	0.515	1.225	0.675	-1.916	2.947
	Multi-taxon	-2.953	1.183	**0.014**	-5.302	-0.604
Orthoptera	Multi-taxon	-3.468	0.949	**< 0.001**	-5.352	-1.584

Note: The bolded *p*-values present the statistical significance in the abundance of arthropods in different orders at $P < 0.05$.

CI, confidence interval; s.e., standard error.

Arthropod community response is, therefore, a critical component of understanding the influence of land use and management interventions on the savanna ecosystems (Hoffmann 2010; Van Wilgen et al. 2017). Furthermore, the groups of arthropods are key organisms that facilitate the ecological processes, and their diversity will influence the rates at which the processes are facilitated in the protected savanna ecosystems.

Conclusion

The sensitivity of arthropod groups to the savanna management techniques (e.g. fire and mammal herbivory) differs and extreme pressure compromises the abundance while boosting the species richness of arthropods in the protected areas. Fire and mammal herbivory affect the composition of the ecological primary producers in the ecosystems (e.g. plants), which alternately affect arthropods within the food webs. The direct and indirect impacts of fire and mammal herbivory pose a threat to rare and threatened insects. Elimination of arthropods affects the overall functioning of a savanna ecosystem. This review showed that the resilience of arthropods varies among orders; however, all groups were equally impacted by fire and mammal herbivory. Policies encouraging the maintenance of undisturbed, minimally and heavily disturbed sections within protected areas optimise the conservation of arthropods. More studies on the impact of fire and mammal herbivory need to be conducted in different landscapes to enhance the knowledge to ascertain the contribution of policies in the conservation of these biological organisms. Although multiple studies assessed the impact of annual and triennial prescribed fires, resources need to be devoted towards assessing the impact of biennial and quadrennial burning cycles on arthropods. Furthermore, studies need to also document the impact of late summer and late winter burns on arthropods. Continuous assessments would be relevant for the continuous cataloguing of arthropods and for monitoring a possible shift in the communities of arthropods. A noticeable shift in biodiversity would lead to rapid change in the policy and integrated management approaches to optimise the conservation of arthropods in the changing environments.

Acknowledgements

The authors would like to thank Prof. Victor Mlambo at the School of Agriculture at the University of Mpumalanga for the inputs that significantly improve the readability and technical aspects of the manuscript. Gratitude is given to Dr Tinyiko Shivambu from the University of South Africa for his useful comments on the earlier version of the manuscript. The University of Mpumalanga, Institutional Research Theme (IRT: Biodiversity Conservation and Development), the University of Free State and the National Research Foundation of South Africa are thanked for their financial support.

Competing interests

The authors reported that they received funding from the Institutional Research Theme (IRT: Biodiversity Conservation and Development) of the University of Mpumalanga, National Research Foundation of South Africa and the University of the Free State, which may be affected by the research reported in the enclosed publication. The authors have disclosed those interests fully and have implemented an approved plan for managing any potential conflicts arising from their involvement. The terms of these funding arrangements have been reviewed and approved by the affiliated university in accordance with its policy on objectivity in research.

Authors' contributions

L.M. and F.C. assisted with a substantial contribution to the conception, study design, acquisition of data, analysis, interpretation and drafting of the manuscript. M.N. was involved in drafting the manuscript. All authors, L.M., M.N. and F.C. read and approved the final article.

Funding information

The authors reported that the study was funded by the Institutional Research Theme (IRT: Biodiversity Conservation and Development) of the University of Mpumalanga, National Research Foundation (Grant no. 119N4588) of South Africa and the University of the Free State (Grant no. 119DD2789).

Data availability

The authors confirm that the data supporting the findings of this study are available within the article.

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