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The effect of fire on soil oribatid mites (Acari: Oribatida) in a South African grassland*

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Abstract

Fire is a natural disturbance factor in southern African grasslands, and has become an important management tool for conservation of these habitats. Information on the impact of fire on any aspect of biodiversity will assist land managers to make more informed decisions on a fire regime that will conserve biodiversity in these grasslands. This is the first study to examine the responses of mite assemblages to fire disturbance in South African grasslands. The study was conducted in the Erfenis Dam Nature Reserve in central South Africa. An area of the Reserve was burned with a fast, hot fire while another area was left unburned as a control. Soil oribatid mites were collected over a period of one year from the burned and control areas. Oribatid assemblages exhibited seasonal patterns, with species richness and abundance slightly higher in early and late autumn and early spring. Four months after fire, there was no residual effect of fire on total abundance and species richness. However, species composition and the seasonal relative abundances of particular species, e.g. *Multioppia wilsoni* Aoki, 1964, *Scheloribates confusia* Coetzer, 1968 and *Anellozetes auriculatus* (Mahunka, 1984), differed between burned and control plots, demonstrating how targeted species can be investigated as indicators of post-fire recovery.

Key words: Soil arthropods, Acariformes, burning effect, conservation, indicators.

Introduction

The Grassland Biome constitutes 28% of the vegetation of South Africa, Lesotho and Swaziland (Rouget *et al*., 2006). It is also the most threatened biome in South Africa (Mucina *et al*., 2006). Only 2.2% of grassland vegetation is currently protected in parks and reserves, ca. 35% has been lost through habitat transformation and degradation, and the rest is under threat from agricultural activities (Mucina *et al*., 2006).

Fire is important for the conservation and management of grasslands (Swanepoel, 1981; Parr *et al*., 2004; Mucina *et al*., 2006), with the frequency, seasonality and intensity of fires being fundamental attributes determining its effects on biota (Mucina *et al*., 2006). Fire removes litter and promotes new nutritious growth of grasses, which results in improved feeding conditions for mammalian grazers and other herbivores including arthropods (Lubin & Crouch, 2003; Barratt *et al*., 2006). Burning also prevents the incursion of woody plants (Lubin & Crouch, 2003). Fire exclusion studies in southern Africa have indicated that in the absence of fire there was a successional trend towards shrub- or forest- vegetation (Mucina *et al*., 2006).

The optimal burning frequency in grasslands in South Africa differs according to the rate of litter accumulation, which in turn is largely determined by the annual rainfall (Manry & Knight, 1986). In general, managed grasslands in South Africa are control-burned every one to four years in late winter, from July to September (Mucina *et al*., 2006). Fire frequency is mainly responsible for the current distribution of terrestrial plant communities in South Africa (Manry & Knight, 1986) but less is known about its effects on faunal diversity. In a study on African savanna ants,

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burning and the frequency of burning did not have a significant effect on species richness and abundance although the ant species composition differed between burned and control plots (Parr *et al*., 2004). Fire also impacts small mammal community structure as it changes with succession (Ferreira & Van Aarde, 2000; Avenant, 2005), and past fire frequency is expected to have contributed towards shaping the current small mammal species assemblages in the Southern African grasslands (Swanepoel, 1981). More information on the impact of fire on biodiversity is required so that land managers can make more informed decisions on a fire regime which will conserve biodiversity in grasslands.

Soil oribatid mites (in the traditional sense, excluding Astigmata, Krantz & Walter, 2009) are an integral part of most grassland ecosystems (Seastedt, 1984a; Yeates & Lee, 1997), where they are numerically abundant and play important roles in decomposition and mineralization of dead plant material, nutrient cycling, and in maintaining soil structure. Several studies have examined the effects of existing management practices on soil microarthropods, e.g. mulching and mowing of mountain meadows (Pižl & Starý, 2001) and urban lawns (Keplin, 1995), forest regeneration practices in France (Cancela da Fonseca, 1990), fire regime in phrygana vegetation in Greece (Sgardelis & Margaris, 1993), oak-hickory forest in Ohio, USA (Dress & Boerner, 2004), tropical rain forest in French Guyana (Betsch & Cancela da Fonseca, 1995) and in *Calluna*-heathland soil in England (Webb, 1994). Nevertheless, microarthropods are seldom taken into consideration in management practices.

The current study is the first to examine the response of mite assemblages to fire disturbance in natural grasslands in South Africa. The aim of the study was to determine if and how oribatid mite abundance and species composition differ between a burned (treatment) and unburned (control) grassland.

Materials and Methods

Study area

The 4,000 ha Erfenis Dam Nature Reserve (including the 3,300 ha dam; 28º30'S; 26º48'E) is situated in the Free State Province, central South Africa. Large mammals (all natural, reintroduced antelope) and virtually the full central grassland complement of native small mammals, birds, reptiles, and small to medium sized predators are expected to reside in the reserve. The most common grasses in the reserve are *Themeda triandra* (red grass), *Heteropogon contortus* (spear grass), *Aristida bipartita* (rolling grass), *Brachiaria eruciformis* (sweet signal grass), *Cymbopogon plurinodis* (narrow-leaved Turpentine grass), *Elionurus muticus* (wire grass) as well as various herbs and shrubs.

A ca. 80 ha rectangular plot in the eastern part of the reserve was burned on 20 September 2005 according to the conservation management policy of the reserve (Lotze, 2008). For scientific purposes, a ca. 70 ha rectangular, adjacent control plot was left unburned. Neither of these plots had been burned for at least seven years prior to the September 2005 fire (R. Lotze *pers. comm.*). Eight months after the fire (May 2006) the average Ecological Value index (reflecting the ecological status and coverage of grasses: Vorster, 1982; Van Rooyen, 2002) in the burned area surpassed that in the control area (E. Schulze, unpub. data).

The study area was situated in a summer rainfall area with mean long-term annual rainfall of 558 mm (Weather Bureau, 1986) and of 762 mm in 2006, inside the reserve. Soil temperature was measured at 5 cm below ground level with a soil thermometer at the specific points where and when the soil samples were taken in 2006 (mean soil temperatures, n= 18: 23/1= 32°C, 6/3= 30°C, 28/4= 15°C, 9/5= 9°C, 1/9= 15°C, 5/12= 23°C).

Sampling

The first soil samples were taken four months after burning (January 2006) and continued until December 2006 for a total of six sampling events separated by one to four months. The sampling dates 23/01, 06/03, 28/04, 09/05, 01/09 and 05/12 are used as "names" for the sampling events. During each event, 9 samples were taken in the central parts (at least 150 m from the edges) of both the burned and control plots. A hand spade was used to get an approximately 250 g, 5 cm deep soil sample. These samples were taken haphazardly, but at least 20 m apart. Mites were extracted from samples for 48 hours using Tullgren funnels. Mites were stored in a solution of 70% alcohol and 5% glycerol and are housed in the Acarology collection of the National Museum, Bloemfontein. Only oribatid mites were identified and used in analyses, since other mites were rarely found in the samples. Identification was done to the lowest possible taxonomic level using Balogh & Balogh (1992) and South African literature.

Analyses

Generalized linear models (McCullagh & Nelder, 1989) were used to determine the relation between the dependent variables (oribatid mite species richness, abundance) and explanatory variables (date sampled, burned/control). A Poisson error distribution was assumed for species richness and abundance, a logarithmic link function was used and deviance used as a measure of goodness of fit (Dobson, 2001). Statistica® (Stat Soft, Inc. 2000) was used for the analyses. A 95% level ($p< 0.05$) was regarded as statistically significant for all tests.

The mean relative abundance for each species in the burned and control plots was calculated (across all samples). Thereafter, mean relative abundance plots across sample dates were constructed for species which showed a difference of more than ten in mean relative abundance between treatments (as determined through graph analysis of the mean relative abundance plot mentioned above).

Results

A total of 2,552 oribatid mites pertaining to 49 species was collected (45 spp. in the burned plots, 39 in the control plots; see Appendix for a species list).

The date sampled contributed significantly to explain species richness and abundance (species richness: $\chi^2= 11.16$, $p< 0.05$, abundance: $\chi^2= 13.84$, $p< 0.05$) in burned and control plots (similarities/differences between dates within treatments are indicated by letters in Fig. 1). In general, species richness and abundance were slightly higher in the 28/4, 9/5 (autumn) and the 1/9 (early spring) samples. The burned/control variable did not contribute significantly to explain mite species richness or abundance (species richness: $\chi^2= 0.58$, $p= 0.45$, abundance: $\chi^2= 1.77$, $p= 0.88$).

Mean relative abundances of soil mite species (summed across all samples per treatment) showed apparent differences between the burned and control plots (through graph analysis) (Fig. 2). The mean relative abundance of the dominant species is as follows (dominant species taken as species with mean abundance more than 20 summed across all samples): *Neoliodes terrestris* (Wallwork, 1963) (Burned= 37.7, Control= 25.0), *Pedrocortesella parva* Pletzen, 1963 (Burned= 25.0, Control= 21.7), *Multioppia wilsoni* Aoki, 1964 (Burned= 28.5, Control= 8.8, significantly different $p< 0.05$), *Anellozetes auriculatus* (Mahunka, 1984) (Burned= 24.5, Control= 12.0), *Arthrodamaeus johanni* Hugo, 2010 (Burned= 20.5, Control= 15.0), *Scheloribates confusia* (Burned= 18.2, Control= 4.2, significantly different $p< 0.05$), *Anellozetes neonominatus* (Kok, 1967) (Burned= 11.5, Control= 9.0) and *Tectocepheus velatus* (Michael, 1880) (Burned= 8.3, Control= 12.2, significantly different $p< 0.05$).

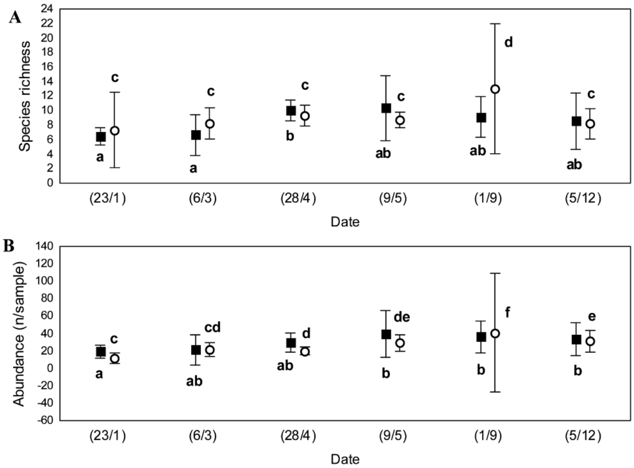

FIGURE 1. Mean (± SE) soil mite species richness (A) and abundance (B), across different 2006 sampling dates in burned (■) and control (○) plots (N= 9 samples for each plot type for each date; weighted means ± 95% confidence intervals). Different letters indicate significant differences between dates sampled within burned and control plots, as determined by generalized linear models (*p*< 0.05); significant differences between burned and control plots on each date sampled were not observed.

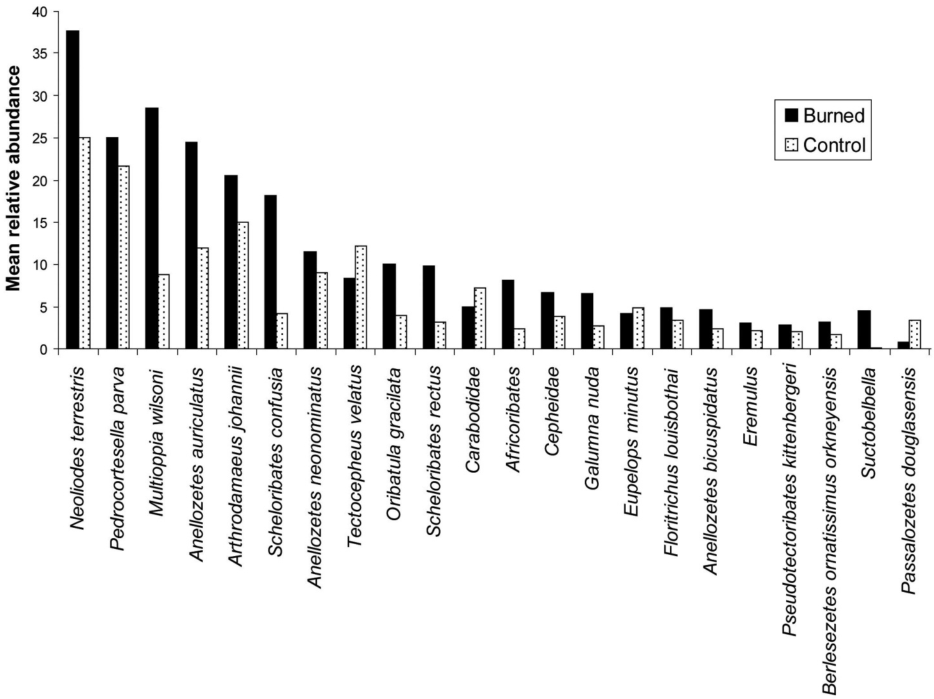

FIGURE 2. Mean relative abundances of mite species in burned and control plots. Species are ranked in order of most to least abundant; species with mean abundance less than four were not included in the graph. Erfenis Dam Nature Reserve, Free State Province, South Africa.

Individual species abundances showed a variety of responses in the first 15 months after fire (species with a difference in mean abundance of more than ten between treatments, according to Fig. 2, are highlighted and shown in Fig. 3). *Neoliodes terrestris* abundance had a peak in the burned plots in month four, after which it slowly decreased. *Multioppia wilsoni* had a sharp increase in abundance in burned plots between months six and seven, and a sharp decrease after month 12. *Anellozetes auriculatus* had high abundances in the burned plots in month seven and eight. *Scheloribates confusia* had higher mean abundances in the burned plots (except for month 12), but without a clear peak.

Discussion

Seasonal variation in oribatid mite abundance and species richness has been confirmed by various studies and explained in terms of the reproductive cycles of mites and/or optimum conditions in terms of moisture content and temperature (Haarløv, 1960; Olivier & Ryke, 1965; Wallwork *et al*., 1986). Understandably these fluctuations varied across studies. For example, mite abundance in forests in Greece was highest from middle spring to early summer (Stamou & Sgardelis, 1989), on Sagar Island in West Bengal, mite populations peaked two times during the year, in late spring and early autumn (Sanyal & Bhaduri, 1982) and in England moorland soils, mite abundances were highest in late spring and early winter (Block, 1966). Two studies in cultivated grasses in summer rainfall areas in South Africa showed that, in general, oribatid mite populations reached peak abun-

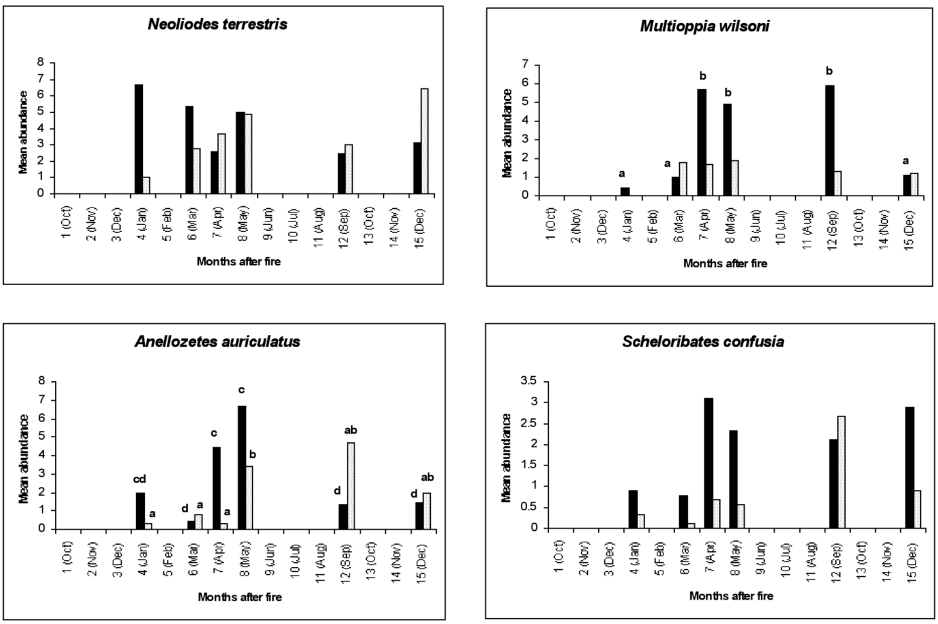

FIGURE 3. Changes in dominant mite species mean abundances in burned (solid bars) and control (dotted bars) plots. Different letters indicate significant differences between dates ($p< 0.05$) within each plot type, as determined by generalized linear models. Differences in mean abundances between burned and control plots were observed only for *A. auriculatus* at month 12 and *S. confusia* at month 6. Erfenis Dam Nature Reserve, Free State Province, South Africa.

dances during late summer and autumn (Loots & Ryke, 1966; Van Nieuwenhuizen *et al*., 1994). This is in agreement with the results of the present study, in which mite species richness and to a lesser extent abundance were the highest in middle (28/4) and late (9/5) autumn and early spring (1/9) in the control plots. Although it appears that these fluctuations are similar to that found for rodents in Free State grasslands and related to temperature and the annual build-up of vegetation (Avenant *et al*., 2008), our sampling protocol (not monthly or on regular intervals) preclude us from making any correlations with soil temperature or rainfall (as soil moisture was not tested).

Various things can happen to soil mites during a fire. Some mites on the surface might be killed instantly due to the heat (Madge, 1965; Malmström, 2008), while more deaths may follow soon after due to the changed microclimate. Mites with a thick cuticle may be able to withstand the heat better than others (Wikars & Schimmel, 2001), or survive by maintaining their body temperature through evaporative cooling (Madge, 1965). They can also migrate to deeper layers in the soil (Kudryasheva & Laskova, 2002; Moretti *et al*., 2006), where they are buffered through the good insulating properties of the upper layers of soil and litter (Webb, 1994; Dress & Boerner, 2004).

The fire that occurred on September 2005 (this study) can be described as a very fast fire which spread rapidly across the landscape. The period during which a particular spot on the surface was subjected to the maximum temperature of the fire was, therefore, short, and it is expected that not all mites were killed during the fire (Webb, 1994). Indeed, Malmström (2008) found that some individuals of oribatid species such as *Tectocepheus* survived temperatures of up to 40ºC. When conditions in the burned area became favorable, the area was probably re-colonized by mites that survived the fire as well as mites from adjacent unburned areas (Kudryasheva & Laskova, 2002; Moretti *et al*., 2006). This probably allowed the mean abundance of oribatid mites in the burned plots to reach similar levels to the mean abundance in the control plots shortly after the fire.

The majority of studies on the effect of fire on mite populations have shown lower abundances in the burned areas for a relatively long time after fire. In indigenous grassland in New Zealand, for example, mite abundance was still lower in the burned areas after three years (Barratt *et al*., 2006). Similar observations were made after one year in tallgrass prairie in Kansas, USA (Seastedt, 1984b), two years in phrygana vegetation in Greece (Sgardelis & Margaris, 1993) and four years in spruce and pine boreal forests in Russia (Kudryasheva & Laskova, 2002). However, in burned shrub vegetation in Georgia, mite species richness and densities showed recovery within four to six months after fire (Murvanidze *et al*., 2008). In the current study, both abundance and species richness never differed significantly between burned and control plots in the period 4–15 months after fire.

Individual species, however, showed idiosyncratic responses to fire. For instance, species like *M. wilsoni* and *S. confusia* were more abundant in the burned plots compared to the control plots, whereas for *Tectocepheus velatus* the opposite was true. These trends in abundances differed from the seasonal trends observed in the control plots and indicate that these species show potential as indicator species. Different responses of oribatid mite species to fire were also observed in various other studies. In prairie in Wisconsin, abundances of *Eremobelba*, *Eobrachychthonius* and *Trichoppia* increased in burned areas (Lussenhop, 1976). This was attributed to an increase in plant growth and microbial activity areas after burns. Some oribatid mite species in burned areas in shrub and forest vegetation in Georgia recovered quickly after fire (Murvanidze *et al*., 2008). Species such as *Tectocepheus*, *Punctoribates punctum* (Koch, 1839), *Fosseremus lacinatus* (Berlese, 1905) and Oppiidae species, which are ubiquitous and wide spread taxa that can tolerate extreme conditions, were the first to recover and colonize burned areas (Murvanidze *et al*., 2008). In several studies, *T. velatus* was found to be tolerant of high temperatures (Malmström, 2008) and was one of the first species to recover after fire (Webb, 1994; Murvanidze *et al*., 2008). This does not seem to be the case in this study (or for at least from four months onwards after the fire). In a study of burned phryganic vegetation in Greece, *Scheloribates pallidulus latipes* (Koch, 1844) was found to occur in higher numbers under stones than under shrubs, thus implying that the stones were protected microhabitats during and after fire (Sgardelis & Margaris, 1993). Consequently, the unique responses of species such as *Scheloribates*, *Multioppia* and *Tectocepheus* in this and other studies reveal their potential as ideal indicator species of ecosystem restoration. Such species should be further investigated in grasslands in South Africa.

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APPENDIX. List of species sampled and their abundances in the burned and control plots at each sampling event. Erfenis Dam Nature Reserve, Free State Province, South Africa [names after Subías, 2004 (2010) and Niedbala, 2006].

Species	Treatment	23/1	6/3	28/4	9/5	1/9	5/12
Cosmochthoniidae							
Cosmochthonius cf. *lanatus* (Michael, 1885)	Burned	-	-	-	1	-	-
	Control	-	-	-	1	-	1
Epilohmanniidae							
Epilohmannia pallida Wallwork, 1962	Burned	-	1	-	-	-	-
	Control	-	-	-	-	2	-
Lohmanniidae							
Cryptacarus promecus Grandjean, 1950	Burned	-	3	-	-	-	-
	Control	-	3	-	-	-	-
Euphthiracaridae							
Acrotritia comteae (Mahunka, 1983)	Burned	-	-	1	-	-	-
	Control	-	-	-	-	-	-
Phthiracaridae							
Atropacarus (Hoplophorella)	Burned	-	2	6	2	-	2
hamatus (Ewing, 1909)	Control	1	4	-	1	-	3
Hermanniellidae							
Hermanniella congoensis Balogh, 1958	Burned	1	-	-	-	-	2
	Control	-	-	-	-	-	-
Neoliodidae							
Neoliodes terrestris (Wallwork, 1963)	Burned	60	48	23	45	22	28
	Control	3	25	11	44	9	58
Licnodamaeidae							
Pedrocortesella africana Pletzen, 1963	Burned	-	-	-	-	-	1
	Control	-	1	-	-	1	-
Pedrocortesella parva Pletzen, 1963	Burned	6	13	16	28	62	25
	Control	10	16	17	11	36	40
Gymnodamaeidae							
Arthrodamaeus johanni Hugo, 2010	Burned	19	23	19	27	7	28
	Control	1	37	6	20	4	22
Gymnodamaeus sp.	Burned	-	-	1	-	-	1
	Control	-	-	-	-	-	-
Cepheidae							
Cepheidae sp.	Burned	23	-	3	2	2	10
	Control	4	13	-	-	3	3
Microzetidae							
Berlesezetes ornatissimus orkneyensis	Burned	-	1	6	4	3	5
(Engelbrecht, 1972)	Control	-	2	-	7	-	1
Astegistidae							
Furcoppia longiseta Grobler, 2003	Burned	1	-	-	1	5	-
	Control	-	1	-	1	-	2
Eremulidae							
Eremulus sp.	Burned	-	1	9	2	5	1
	Control	-	1	-	8	3	1
Damaeolidae							
Fosseremus laciniatus (Berlese, 1905)	Burned	-	-	-	2	-	-
	Control	2	4	1	-	1	1
Eremobelbidae							
Eremobelba sp.	Burned	-	-	-	-	-	-
	Control	-	1	-	-	-	-
	Control	-	-	-	-	-	-
Oppiidae							
Oppiidae sp.	Burned	-	-	-	1	-	-
	Control	-	-	-	-	-	-
Neoamerioppia africana (Kok, 1967)	Burned	-	-	-	-	-	-
	Control	-	5	-	1	-	-

Species	Treatment	23/1	6/3	28/4	9/5	1/9	5/12
Lasiobelba neonominata (Kok, 1967)	Burned	3	2	4	1	3	1
	Control	-	1	-	1	-	-
Multioppia wilsoni Aoki, 1964	Burned	4	9	51	44	53	10
	Control	-	16	5	17	4	11
Brachioppiella (Gressittoppia)	Burned	-	-	-	7	-	-
orkneyensis (Kok, 1967)	Control	-	-	-	-	-	-
Kokoppia longisetosa (Kok, 1967)	Burned	-	-	3	-	1	-
	Control	-	-	-	-	-	-
Suctobelbidae							
Suctobelbella sp.	Burned	2	-	10	9	6	-
	Control	1	-	-	-	-	-
Carabodidae							
Austrocarabodes hendriksi Hugo, 2008	Burned	-	-	-	1	-	-
	Control	-	-	-	2	-	-
Carabodidae sp.	Burned	7	3	2	8	3	7
	Control	5	1	-	12	3	22
Tectocepheidae							
Tectocepheus velatus (Michael, 1880)	Burned	2	4	9	10	-	25
	Control	1	14	3	36	4	15
Passalozetidae							
Passalozetes douglasensis Engelbrecht, 1974	Burned	-	-	-	3	1	1
	Control	-	2	-	15	-	3
Phenopelopidae							
Eupelops minutus Grobler, 1989	Burned	-	1	2	17	4	1
	Control	2	1	3	2	15	6
Achipteriidae							
Pseudotectoribates kittenbergeri	Burned	-	2	-	4	-	11
(Balogh, 1959)	Control	-	2	-	8	-	2
Humerobatidae							
Africoribates sp.	Burned	-	25	-	9	-	15
	Control	-	8	-	5	-	1
Anellozetes sp.	Burned	-	-	-	-	-	-
	Control	-	1	-	-	-	-
Anellozetes auriculatus (Mahunka, 1984)	Burned	18	4	40	60	12	13
	Control	1	7	1	31	14	18
Anellozetes bicuspidatus (Mahunka, 1985)	Burned	-	19	2	-	1	6
	Control	-	-	1	11	-	2
Anellozetes neonominatus (Mahunka, 1985)	Burned	-	-	9	1	56	3
	Control	-	8	-	15	5	26
Zetomotrichidae							
Floritrichus louisbothai Coetzee, 2003	Burned	3	3	11	2	8	2
	Control	-	5	-	1	3	11
Zetomotrichus lacrimans Grandjean, 1934	Burned	-	-	-	-	-	-
	Control	1	-	1	-	2	-
Oribatulidae							
Oribatula (Zygoribatula) gracilata	Burned	-	5	6	13	11	25
(Grobler & Kok, 1993)	Control	-	3	2	3	1	15
Scheloribatidae							
Scheloribates sp.	Burned	-	-	2	5	-	-
	Control	-	-	-	-	-	-
Scheloribates confusia Coetzer, 1968	Burned	8	7	28	21	19	26
	Control	1	1	2	5	8	8
Scheloribates cf. *obtusus* Pletzen, 1963	Burned	-	-	-	-	-	1
	Control	-	-	-	-	-	-
Scheloribates parvus Pletzen, 1963	Burned	-	-	-	-	1	-
	Control	1	-	-	-	1	-
Scheloribates rectus Hammer, 1958	Burned	7	2	6	6	5	33
	Control	2	5	1	2	2	7

Species	Treatment	23/1	6/3	28/4	9/5	1/9	5/12
Scheloribates cf. *tricarinatus* Coetzer, 1968	Burned	-	-	-	-	1	-
	Control	-	-	-	-	-	-
Haplozetidae							
Afroleius simplex Mahunka, 1984	Burned	-	1	-	5	-	1
	Control	-	-	2	1	-	-
Indoribates (Haplozetes) sp.	Burned	8	4	-	5	-	4
	Control	-	-	1	-	-	-
Galumnidae							
Galumna nuda Engelbrecht, 1972	Burned	3	9	-	9	-	18
	Control	-	5	3	3	-	5
Pergalumna sp.	Burned	-	-	-	1	-	-
	Control	-	-	-	-	-	-
Pergalumna elongata Engelbrecht, 1972	Burned	1	-	-	2	-	-
	Control	-	-	-	-	-	-