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# Importance of using many taxa and having adequate controls for monitoring impacts of fire for arthropod conservation

James S. Pryke · Michael J. Samways

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**Abstract** Fire is a key natural and anthropogenic disturbance factor across many ecosystems, and also an important conservation management tool. However, little is known about arthropod responses to fire, particularly in Mediterranean-type ecosystems, including the biodiverse Cape Floristic Region (CFR). We investigate here the relative variety of responses by different arthropod taxa to fire, and ask whether single-taxon or multi-taxa approaches better suit post-fire biomonitoring for conservation management. Sampling involved multiple techniques and was conducted before fire, 1 year after fire, and 3 years after fire, with unburned areas as controls. Before-and-after statistics were used to identify changes in arthropod populations and assemblages as a result of fire, and between treatment and control sites. However, this was against a background of the annual effects having a major influence on the arthropods, irrespective of fire. Abundance was so variable, even in control plots, that we found it an unreliable indicator of the impact of fire. Overall, arthropods were remarkably resilient to fire, with most taxa recovering in species richness and assemblage composition within 3 years of the fire. Although all taxa showed resilience to fire, there was nevertheless little congruence in temporal recovery of the various taxa. Our results highlight the shortcomings of monitoring fire impacts using only a single-taxon without prior testing for complementarity or sensitivity to fire, while emphasizing the importance of sampling a wide range of taxa to represent overall responses of compositional biodiversity. From this, we

recommend, at least for the CFR, that a cross-section of taxa, such as butterflies, ants, and scarab beetles, be used for monitoring arthropods in recovery/fire management conservation programmes. We also recommend that such monitoring be considered against the background of large annual variation seen in unburned areas.

**Keywords** Invertebrates · Arthropods · Insects · Responses · Fire · Conservation · Cape Floristic Region

## Introduction

Besides climate and soil, fire is one of the most important factors determining the composition of many ecosystems and their distributions (Bond and Keeley 2005; Bond et al. 2005), and an important conservation tool in fire prone areas (Parr and Andersen 2006; Driscoll et al. 2010). Fire is a major natural event in many grasslands, savannas, forests, as well as Mediterranean-type ecosystems, including the Cape Floristic Region (CFR) (Parr and Chown 2003). Information on the effects of fire on various taxa is important for making appropriate decisions on fire management for optimal biodiversity conservation, especially as fire is often used as a conservation management tool for regenerating local vegetation after anthropogenic disturbances, such as logging in Finland (Toivanen and Kotiaho 2007) and Australia (Penman et al. 2008), and alien vegetation clearing in the CFR (Holmes et al. 2000). However, while fire is natural process in the CFR, most fires in the area are started as a result of arson or unintentionally by people (Forsyth and van Wilgen 2008).

New et al. (2010) emphasized that the effects of fire can be complex. For example fire frequency has been reported to have detrimental effects on local invertebrate

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assemblages (Andersen and Muller 2000; Andersen et al. 2005; Coleman and Rieske 2006; Swengel and Swengel 2007). As biodiversity consists mostly of arthropods, we need to sample these less charismatic animals if we aim to conserve biodiversity as a whole. Vegetation has been used as a surrogate for arthropod biodiversity in fire management, although research has shown little or no congruence between plant and arthropod diversity (Panzer and Schwartz 1998).

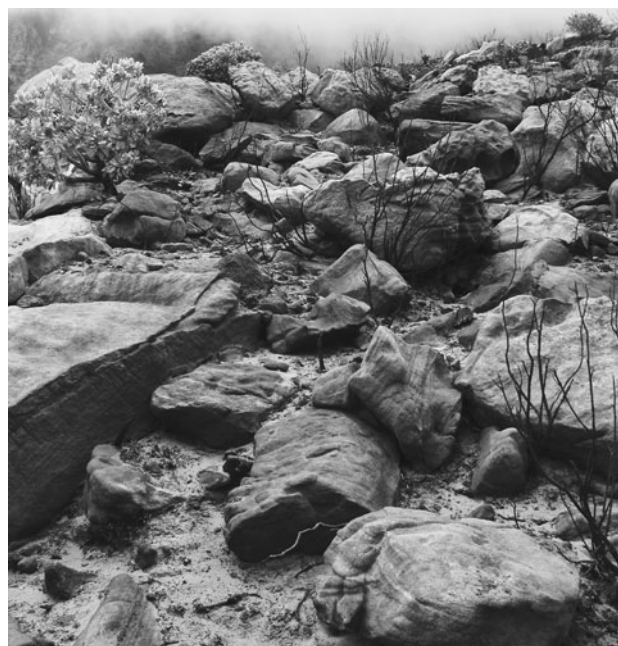
Very few studies have examined the responses of various arthropod groups to fire in the biologically important CFR. This study aims to focus on a wide range of arthropod taxa in the CFR and investigate their differential recovery times from pre-fire to 3 years after a burn. From this we will be able to choose the right taxa that will then enable us to better monitor the effects of fire for conservation management of biodiversity in the Cape Floristic Region. Furthermore, we also ask whether single-taxon or multi-taxon approaches better suit post-fire biomonitoring for conservation management.

## Methods

### Study area and site selection

The study area was the Table Mountain National Park (TMNP) on the Cape Peninsula (33°58' S; 18°24' E), which is dominated by Peninsula Granite Fynbos, and Peninsula Sandstone Fynbos. Twelve to fifteen year burn cycles have been identified as appropriate for the fynbos, based on the response of Proteaceae (van Wilgen et al. 1992), with a varied burning regime being preferred to maximise biodiversity (Seydack et al. 2007). Although most of the current fires occur during summer and autumn, which is the most ecologically acceptable time of year for fires, it is their frequency which is of major concern (van Wilgen et al. 1992; Forsyth and van Wilgen 2008). Table Mountain (ca. 55 km<sup>2</sup>) is one of the most intensively burned areas of the Cape Peninsula, with some areas having an average fire frequency of under 7.5 years between fires over the last 38 years (Forsyth and van Wilgen 2008). Table Mountain is an area of high conservation priority due to its high numbers of Red-Listed invertebrate species (Pryke and Samways 2009a).

Sampling was first conducted in early January 2006 at ten sites (five on the west of Table Mountain and five on the north). Shortly afterwards, there were two major accidental fires on the mountain fortuitously burning six sites. These were typical of fires of the region where much of the low lying shrubs burned, with some woody vegetation both dead and alive remaining (Fig. 1). This remnant vegetation, along with the rocky nature of the area, creates micro-refugia for the arthropods (Fig. 1). This contrasts with fires



**Fig. 1** Remnant vegetation immediately after fire, and the presence of rocky micro-refugia for arthropods in the study area

of flat grasslands, where most of the above-ground vegetation biomass is removed, and arthropods would have to recolonise or re-emerge over a much larger spatial scale. One of these fires burned a large patch (ca. 2.6 km<sup>2</sup>) of the vegetation on the west side of Table Mountain, affecting three sites, and another burned more than half the north side (ca. 1.8 km<sup>2</sup>) of the mountain, also burning three sites. In total, there were six treatments (burned) sites and four control sites. These sites were at least 400 m apart and 400 m from the edge of the burned area. Due to the size of Table Mountain, 400 m represents the maximum distance which five sites per side (10 in total) could fit without interference from other factors, such as the urban areas at the base of the mountain. This distance should be adequate to prevent pseudoreplication from most invertebrate groups, with only the most active and mobile of the butterflies and dragonflies able to fly between these distances. These exact sites were then sampled again 1 year after the fire (January 2007) and 3 years after the fire (January 2009), giving a total of 30 sampling events. Altitude, vegetation type and aspect for all sites were kept constant to eliminate effects due to these variables. Sampling was only conducted on sunny and windless days.

### Arthropod sampling

Three different surface-active and two different aerial sampling techniques were employed to capture many different species (Olson 1991; Druce et al. 2004; Jimenez-Valverde and Lobo 2005; Snyder et al. 2006). The

sampling techniques were pitfall trapping, quadrat searches, Berlese-Tullgren funnel litter extractions, aerial surveys and window trapping.

All species of Arachnida (except mites), terrestrial Malacostraca, Myriapoda, Odonata, Blattodea, Orthoptera, Mantodea, Phasmatodea, Neuroptera, Lepidoptera (only butterflies), Hymenoptera and the Coleoptera families: Carabidae, Scarabaeidae, Trogidae and Cerambycidae were sampled. For all sampling methods, collected arthropods were sorted, assigned families, and where possible, identified to species. The Isopoda, Chilopoda and Hymenoptera (with the exception of the Formicidae) could only be assigned to morphospecies due to the lack of taxonomic knowledge or expertise to identify these groups.

Each of the ten sites had four pitfall traps arranged in a one metre square. Each trap was 70 mm in diameter, which effectively captures many species of ants (Abensperg-Traun and Steven 1995) and spiders (Brennan et al. 2005). For each of the 30 sampling events, traps were half-filled with a 50% ethylene glycol solution (Woodcock 2005), and were left open for a week, a period considered adequate for ant assemblages (Borgelt and New 2006). Quadrat sampling involved an intensive ground search within a single one metre square quadrat at each of the ten sites over the three sampling periods for all arthropods listed above, which were collected and preserved for identification. The Berlese-Tullgren funnel litter extraction consisted of 725 ml of litter collected at the ten sites over three sampling periods, placed in a sealed plastic bag, and put in a Berlese-Tullgren funnel for 72 h [for more details on the epigeic sampling techniques, see Pryke and Samways (2010)]. Aerial surveys targeted butterflies, Odonata, Scarabaeidae and large Hymenoptera. These surveys consisted of a 5 min period in which all flying insects were recorded. If a specimen was not familiar, it was captured and preserved for later identification. All aerial surveys were conducted by the same person to minimize any differential errors due to sampling effort or relative knowledge. Window traps were custom designed to suit the local environment, particularly the mountain's vegetation height, high wind speeds, steep gradient and rocky terrain. Two traps were erected at each of the ten sites two metres apart, one perpendicular and the other horizontal to the mountain slope. Both were left out for 24 h, after which the sample was drained, and specimens preserved [for more details on the aerial techniques, see Pryke and Samways (2008)].

#### Data analyses

We analysed data for all arthropods together, and also for aerial and surface-active arthropods separately. We then analysed the most abundant taxa: Myriapoda, Malacostraca, Araneae, Orthoptera, Lepidoptera, Carabidae,

Scarabaeidae, Formicidae, Halictidae and the remaining Hymenoptera. We examined species richness in burned and control sites by generating separate species rarefaction curves for all of the above groups per treatment per year with Mao Tao output from EstimateS (version 8; Colwell 2006). We used values of rarefied richness to standardize for differences between sampling years (Gotelli and Colwell 2001), and rarefied species richness to the lowest total number of individuals per treatment per year. Generalized Linear Mixed Models (GLMMs) with Poisson distribution were used to analyse the abundance data (O'Hara 2009; Zuur et al. 2010) in SAS 9.1. GLMMs with Poisson distributions were also used to determine differences in abundance for the 15 most abundant species (representing 75% of overall abundance). As these analyses showed no overdispersion of the variances compared to the models, Wald  $\chi^2$  (Z) statistics were calculated using the penalised quasilielihood technique (Bolker et al. 2009). We tested responses to fire over time, with other test to determine the annual changes in assemblages irrespective of fire and fire versus control per year.

Analysis of similarity (ANOSIM) using Primer v.5.0 (Clarke and Warwick 2001), which assesses changes in assemblage composition, was also calculated for all assemblages and taxa listed above, with treatment and control at pre-fire, 1–3 years after fire intervals as factors. Analyses were performed using Bray-Curtis similarity measures with these data fourth-root transformed to reduce the weight of the common species (Clarke and Warwick 2001). This analysis produces an R-statistic and a *p* value. An R-statistic of zero shows identical assemblages, while unity indicates distinct assemblages [for more details, see Clarke and Warwick (2001)].

#### Results

##### Species richness, abundance and assemblage compositional responses to fire

The overall assemblage, and the surface active arthropod separately, had significantly lower species richness at treatment sites 1 year after fire compared to the control sites at the same time, as well as at sites before and 3 years after fire (Table 1; Fig. 2). The aerial assemblage and the Scarabaeidae showed significantly fewer species in treatment sites compared to control sites 1 year after fire, with these sites also significantly lower 3 years after the fire. Hymenoptera, without the Formicidae or Halictidae, showed significantly lower species richness in treatment sites 1 year after fire compared to the same sites before fire (Table 1).

In contrast to the results for species richness, abundance showed a variety of responses to fire for the different

**Table 1** Summary results from the 139 species (51 families and 16 orders) of rarefied species richness data, Generalized Linear Mixed Models (with Poisson distribution) on means for differences in the abundance of individuals, as well as the results of analysis of similarity for different arthropod assemblages and taxa sampled on Table Mountain

Category	Sites			Time	
	PC vs. PT	C1 vs. T1	C3 vs. T3	Control	Treatment
<b>Species richness</b>					
Overall	PC = PT	C1 > T1	C3 = T3	PC = C1 < C3	PT > T1 < T3
Surface-active	PC = PT	C1 > T1	C3 = T3	PC = C1 = C3	PT > T1 < T3
Aerial	PC = PT	C1 > T1	C3 = T3	PC = C1 = C3	PT = T1 = T3
Araneae	PC = PT	C1 = T1	C3 = T3	PC = C1 = C3	PT = T1 = T3
Malacostraca	PC = PT	C1 = T1	C3 = T3	PC = C1 = C3	PT = T1 = T3
Myriapoda	PC = PT	C1 = T1	C3 = T3	PC = C1 = C3	PT = T1 = T3
Orthoptera	PC = PT	C1 = T1	C3 = T3	PC = C1 = C3	PT = T1 = T3
Carabidae	PC = PT	C1 = T1	C3 = T3	PC = C1 = C3	PT = T1 = T3
Scarabaeidae	PC = PT	C1 > T1	C3 = T3	PC = C1 = C3	PT = T1 < T3
Lepidoptera	PC = PT	C1 = T1	C3 = T3	PC = C1 = C3	PT = T1 = T3
Formicidae	PC = PT	C1 = T1	C3 = T3	PC = C1 = C3	PT = T1 = T3
Halictidae	PC = PT	C1 = T1	C3 = T3	PC = C1 = C3	PT = T1 = T3
Other Hymenoptera	PC = PT	C1 = T1	C3 = T3	PC = C1 = C3	PT > T1 = T3
<b>Abundance</b>					
Overall	PC > PT	C1 = T1	C3 > T3	PC = C1 = C3	PT = T1 > T3
Surface-active	PC > PT	C1 < T1	C3 > T3	PC = C1 > C3	PT < T1 > T3
Aerial	PC > PT	C1 > T1	C3 > T3	PC > C1 < C3	PT > T1 < T3
Araneae	PC = PT	C1 = T1	C3 = T3	PC = C1 = C3	PT = T1 < T3
Malacostraca	PC = PT	C1 = T1	C3 = T3	PC = C1 = C3	PT = T1 = T3
Myriapoda	PC = PT	C1 = T1	C3 = T3	PC = C1 = C3	PT = T1 = T3
Orthoptera	PC = PT	C1 = T1	C3 = T3	PC = C1 = C3	PT = T1 = T3
Carabidae	PC = PT	C1 > T1	C3 > T3	PC = C1 < C3	PT = T1 = T3
Scarabaeidae	PC = PT	C1 > T1	C3 = T3	PC = C1 < C3	PT > T1 < T3
Lepidoptera	PC = PT	C1 = T1	C3 = T3	PC = C1 = C3	PT = T1 = T3
Formicidae	PC > PT	C1 < T1	C3 > T3	PC = C1 > C3	PT < T1 > T3
Halictidae	PC = PT	C1 = T1	C3 = T3	PC > C1 < C3	PT > T1 < T3
Other Hymenoptera	PC = PT	C1 > T1	C3 = T3	PC > C1 = C3	PT > T1 < T3
<b>Similarity (ANOSIM)</b>					
Overall	PC = PT	C1 = T1	C3 ≠ T3	PC ≠ C1 ≠ C3	PT ≠ T1 ≠ T3
Surface-active	PC = PT	C1 = T1	C3 ≠ T3	PC = C1 = C3	PT = T1 = T3
Aerial	PC = PT	C1 = T1	C3 ≠ T3	PC ≠ C1 ≠ C3	PT = T1 = T3
Araneae	PC = PT	C1 = T1	C3 = T3	PC = C1 = C3	PT = T1 = T3
Malacostraca	PC = PT	C1 = T1	C3 = T3	PC = C1 = C3	PT = T1 = T3
Myriapoda	PC = PT	C1 = T1	C3 = T3	PC = C1 = C3	PT = T1 = T3
Orthoptera	PC = PT	C1 = T1	C3 = T3	PC = C1 = C3	PT = T1 = T3
Carabidae	PC = PT	C1 = T1	C3 = T3	PC = C1 = C3	PT = T1 = T3
Scarabaeidae	PC = PT	C1 = T1	C3 = T3	PC ≠ C1 = C3	PT = T1 = T3
Lepidoptera	PC = PT	C1 ≠ T1	C3 = T3	PC = C1 = C3	PT ≠ T1 = T3
Formicidae	PC = PT	C1 = T1	C3 = T3	PC = C1 = C3	PT = T1 = T3
Halictidae	PC = PT	C1 ≠ T1	C3 = T3	PC ≠ C1 ≠ C3	PT ≠ T1 ≠ T3
Other Hymenoptera	PC = PT	C1 = T1	C3 = T3	PC = C1 = C3	PT ≠ T1 ≠ T3

C = control, T = treatment, P = pre-fire, 1 = one year after burn, 3 = three years after burn. = indicates no significant difference, < and > indicate significantly lower or high means respectively, ≠ significant difference in assemblage composition

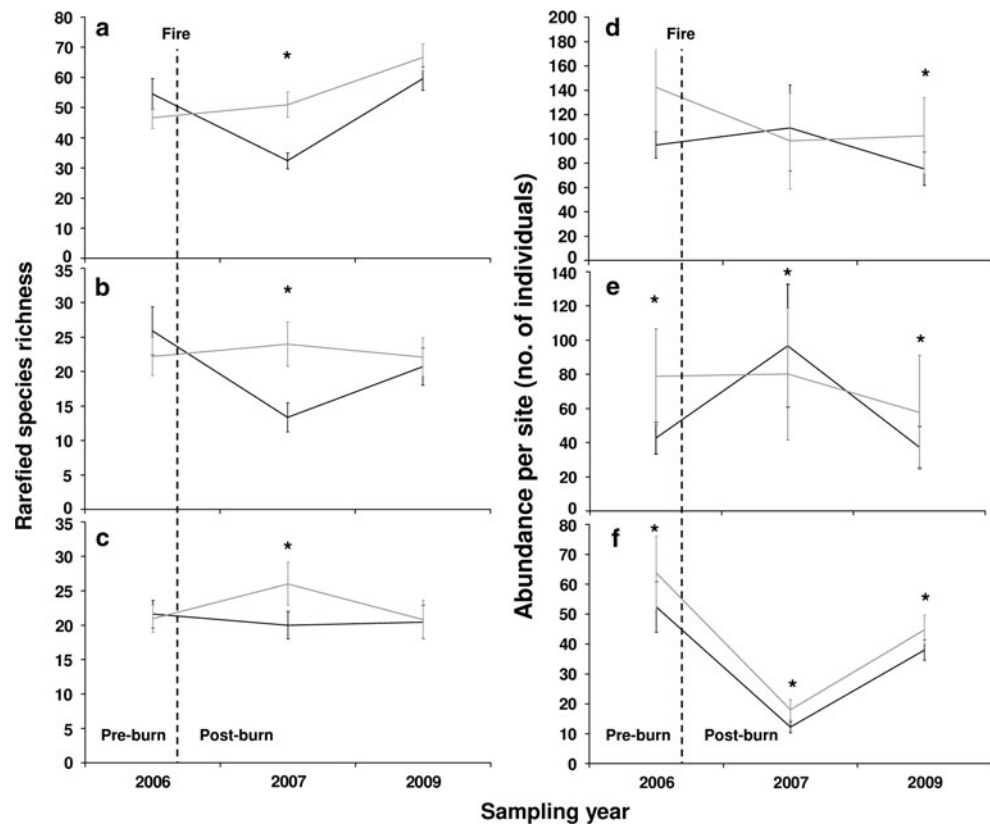
groups (Table 1; Fig. 2). Overall, surface active arthropods, aerial insects and ants all were significantly more abundant in control sites before the burn, while ants were significantly more abundant in burned sites 1 year after the burn, and significantly less abundant three years after the

burn. Carabidae, Scarabaeidae and Hymenoptera (without Formicidae or Halictidae) significantly decreased in abundance in treatment sites as a result of fire (Table 1).

The three general assemblages (overall, surface-active, and aerial) showed significant differences in composition



**Fig. 2** Rarefied species richness ( $\pm 1$  SD) for the overall (a), surface active (b) and aerial (c) arthropod assemblages as well as the mean ( $\pm 1$  SE) abundance for the overall (d), surface active (e) and aerial (f) arthropod assemblages. \* Signifies significance pairwise differences in the rarefied species richness or GLMM (with Poisson distribution) in abundance



of species between control and treatment sites only 3 years after fire (Table 1). Butterfly species composition changes 1 year after the fire between the control and treatment sites and between pre and 1 year post fire in the treatment sites (Table 1).

In total, 3,027 individuals were sampled from 139 species (51 families and 16 orders), 1,671 individuals from 112 species in treatment sites and 1,356 individuals from 105 species in control sites.

#### Individual species response to fire

Certain species, particularly in the Formicidae, showed strong resilience to fire, with *Lepisiota* sp. and *Solenopsis punctaticeps* showing significant increases in relative abundance after fire, with only *Pheidole* sp. being significantly less abundant after fire (Table 2). Halictidae species on the other hand, were less resilient, and decreased after fire. The exception was Sp3, which recovered to its original abundance 3 years after fire (Table 2). Coleopteran species were also resilient, although the scarab *Peritricha nigrata* and the carabid beetle *Thermophilum decemguttatum* were significantly more abundant in control sites compared to treatment sites 3 years after fire (Table 2). The two spider species showed non-significant differences for all comparisons, while the solifuge species *Solpuga* cf. *fusca* was

significantly more abundant in the control compared to the treatment sites one year after fire (Table 2).

#### Discussion

##### Importance of annual variation on the arthropod assemblage

The arthropod assemblages in unburned areas of the CFR vary greatly from year to year. This large annual variation, even in the absence of fire, is similar to the situation with butterflies of the North American prairie (Fleishman 2000), and the terrestrial arthropods of the Australian savanna (Andersen and Muller 2000). Annual variation is a highly influential and well established variable on time-based fire ecology studies that needs to be taken into account, yet is often rarely considered. Here, annual variation was variously important depending on whether abundance, species richness or assemblage composition is being considered. Abundance was a poor indicator of assemblage recovery due to fire, as a result of the major influence that annual variation had on it. Rarefied species richness in contrast, appears to be less susceptible to annual variation, which made interpretation of the effects of fire more reliable than was the case of abundance. Arthropod assemblage

**Table 2** Summary of 15 of the most abundant arthropod species analysed independently in Generalized Linear Mixed Models (with Poisson distribution). Comparisons are given for individual species abundance

Category	Sites			Time	
	PC vs. PT	C1 vs. T1	C3 vs. T3	Control	Treatment
Abundance					
<i>Anoplolepis</i> sp <sup>a</sup>	PC > PT	C1 > T1	C3 > T3	PC < C1 = C3	PT > T1 < T3
<i>Lepisiota</i> sp <sup>a</sup>	PC = PT	C1 < T1	C3 < T3	PC = C1 > C3	PT < T1 > T3
Sp1 <sup>b</sup>	PC > PT	C1 = T1	C3 = T3	PC > C1 < C3	PT > T1 < T3
<i>Solenopsis punctaticeps</i> <sup>a</sup>	PC = PT	C1 < T1	C3 = T3	PC = C1 = C3	PT < T1 > T3
<i>Pheidole</i> sp <sup>a</sup>	PC > PT	C1 = T1	C3 = T3	PC > C1 = C3	PT > T1 = T3
Sp2 <sup>b</sup>	PC = PT	C1 = T1	C3 < T3	PC > C1 = C3	PT > T1 < T3
Sp3 <sup>b</sup>	PC = PT	C1 = T1	C3 > T3	PC = C1 = C3	PT > T1 = T3
<i>Tetramorium</i> sp <sup>a</sup>	PC = PT	C1 > T1	C3 = T3	PC < C1 > C3	PT = T1 > T3
<i>Monomorium</i> sp <sup>a</sup>	PC = PT	C1 < T1	C3 = T3	PC = C1 = C3	PT < T1 > T3
<i>Cyrtothyrea marginalis</i> <sup>c</sup>	PC = PT	C1 = T1	C3 = T3	PC = C1 = C3	PT > T1 = T3
<i>Peritrichia nigrita</i> <sup>c</sup>	PC = PT	C1 = T1	C3 > T3	PC = C1 = C3	PT = T1 = T3
<i>Solpuga</i> cf. <i>fusca</i> <sup>d</sup>	PC > PT	C1 > T1	C3 = T3	PC = C1 > C3	PT = T1 = T3
<i>Hermacha brevicauda</i> <sup>c</sup>	PC = PT	C1 = T1	C3 = T3	PC = C1 = C3	PT = T1 = T3
<i>Enoplognatha</i> sp <sup>f</sup>	PC = PT	C1 = T1	C3 = T3	PC = C1 = C3	PT = T1 = T3
<i>Thermophilum decemguttatum</i> <sup>g</sup>	PC = PT	C1 = T1	C3 > T3	PC = C1 < C3	PT = T1 = T3

Species are ranked in order of abundance and represent 75% of overall abundance

C = control, T = treatment, P = pre-fire, 1 = one year after burn, 3 = three years after burn

<sup>a</sup> Hymenoptera: Formicidae

<sup>b</sup> Hymenoptera: Halictidae

<sup>c</sup> Coleoptera: Scarabaeidae

<sup>d</sup> Solifugae: Solugidae

<sup>e</sup> Araneae: Nemesiidae

<sup>f</sup> Araneae: Theridiidae

<sup>g</sup> Coleoptera: Carabidae

= indicates no significant difference, < and > indicate significantly lower or high means respectively

composition (combined species composition and relative abundance of the various species), was analysed here using ANOSIM showed some variation in the overall assemblage, as well as both surface active and aerial assemblages, between years in the unburned sites (Table 1).

#### Arthropod recovery times after fire

Despite the annual affects, fire has a strong influence on the species richness and arthropod assemblage composition of the CFR. Species richness of the overall assemblage, as well as for surface active and aerial assemblages, decreased in treatment sites 1 year after fire, then recovered after 3 years, a trend not observed in the control sites. These control sites also had significantly higher species richness for the all assemblages (Fig. 2), suggesting that the drop in species richness in treatment sites after 1 year is directly due to fire, with the species richness recovering after 3 years.

Arthropod assemblage composition, changed in response to fire. The overall assemblage, as well as the aerial and surface-active assemblages, still had not recovered to pre-fire levels 3 years after the fire. Interestingly, timing of the fire recovery response was similar to that after removal of alien pine trees in the same area (Pryke and Samways 2009b). In contrast to species richness and arthropod assemblage composition, abundance varied so much between years, irrespective of fire, that coming to conclusions on the effect fire alone had on abundance, was not reliable.

#### Differential response of taxa to the effects of fire

Various taxa responded differently to fire, as in the Australian savanna (Andersen and Muller 2000) and the neotropics (Vasconcelos et al. 2009). The most resilient taxon here was the ants, which showed no change in species richness but a significant increase in abundance in response to fire. These

Mediterranean-type ecosystem results are similar to those on ant assemblages after burning in South African savanna (Parr et al. 2004), Australian grassland (Gunawardene and Majer 2005; Barrow et al. 2007) and savanna (Parr and Andersen 2008), as well as in the neotropics (Vasconcelos et al. 2009). Resilience of ants to fire in the CFR is likely to be due to many of the species in the area nesting below ground and able to retreat into their nests to avoid the fire.

Scarab beetles showed strong responses to fire, with species richness and abundance significantly lower 1 year after fire, but recovered 3 years afterwards. This suggests that Scarabs have potential as indicator groups in the CFR to measure arthropod recovery after fire. Carabid beetles had few responses to fire. These results appear to be restricted to the CFR, as these groups showed no significant changes in response to fire in Australian savanna (Andersen and Müller 2000), neotropical grassland (Vasconcelos et al. 2009), deciduous African forest (Sileshi and Mafongoya 2006), north American prairie (Cook and Holt 2006) or temperate north American forest (Niwa and Peck 2002).

Spiders are greatly affected by fire, with studies in Australian savanna (Andersen and Muller 2000), South African grassland (Lubin and Crouch 2003), neotropical grassland (Vasconcelos et al. 2009) and north American pine forest (Gillette et al. 2008) showing a decrease in spider richness after fire. However, here we found no change in spider assemblage composition, species richness or abundance, suggesting that the spiders of the CFR may be using the micro-refugia offered by rocks and difficult-to-burn plants in the CFR terrain (Fig. 1), as is the case with grasshoppers in the Drakensberg mountains of South Africa (Samways 1990). Wasps and bees (with the exception of the ants and halictid bees), crickets, centipedes and terrestrial crustaceans also appeared to be tolerant of fire, as they showed no significant assemblage composition, species richness or abundance changes due to fire. This is similar to wasp and cricket assemblages in the Australian savanna (Andersen and Muller 2000), and to centipede and terrestrial crustacean assemblages in African deciduous forest (Sileshi and Mafongoya 2006). Although the halictid bee abundance changed on the same sites after fire, this seems to be due to annual changes rather than any real affect of fire, as the control also showed significant changes.

Butterfly responses here were similar to those on north American prairie, which showed greater butterfly assemblage compositional variation between burned areas compared to control sites, yet neither species richness nor abundance changed significantly (Vogel et al. 2007). This is probably a result of specialist butterfly species decreasing and generalist species increasing in response to fire (Swengel 1996). This may also be very important in the CFR, as butterflies, unlike many other arthropods, do not use the micro-refugia of rocks and unburned wood.

## Responses of individual species to fire

The most common species, when analyzed separately, were particularly responsive to fire. Some of the ant species showed low resilience to fire, with *Anoplolepis* sp. and *Tetramorium* sp. showing a significant decline after fire, while *Lepisiota* sp, *Solenopsis punctaticeps* and *Monomorium* sp. significantly increased. The three halictid bee species, in contrast, were much more responsive to annual changes, making it difficult to interpret their response to fire. Other species underwent few significant changes in abundance, with only the flower visiting scarab *Peritrichia nigrita* and the predatory carabid *Thermophilum decemguttatum* showing significantly higher abundance 3 years after fire in control compared to treatment sites. Interestingly, most species either tolerated fire or were equally abundant 1 year later, while the remainder mostly recovered within 3 years.

## Conclusions

Our results show the shortcomings of using an untested single-taxon, particularly at the family level, for monitoring fire impacts, and illustrate the importance of sampling a wide range of taxa for fire conservation management. Similar to Andersen and Müller (2000); Andersen et al. (2005); Sileshi and Mafongoya (2006) and Vasconcelos et al. (2009), these results show that there is a great deal of variation between taxa in response to fire. This suggests that using one taxon to monitor overall invertebrate response to fire could be problematic, unless prior studies have been conducted to establish that it is the most sensitive taxa. Otherwise single taxon studies need to be viewed in the context that they are only presenting the responses for that particular taxon and not for overall biodiversity.

These results show the great importance of considering annual variation, and thus setting up adequate controls when sampling arthropods in time-based fire ecology studies. Of all the groups here, beetles and butterflies were the least resilient to fire. Owing to these differences between taxa, we suggest that a multi-taxa approach is the most reliable means of monitoring arthropod recovery after fire in the CFR. For this purpose, we suggest that the best complementary combination of taxa to monitor, at least in the CFR, is the butterflies, scarab beetles, and potentially the halictid bees, although further work is needed to verify this. As ants are highly resilient and very different to these other taxa in their response to fire, they should only be included as a complementary group. Viewing this another way round, using only ants in fire ecology research and management, at least within the CFR, has severe limitations, particularly in terms of them representing other arthropods.



Overall, the arthropod assemblage here was remarkably resilient to this localized fire, largely recovering after 3 years. This finding supports other studies in fire prone areas (Andersen and Müller 2000, Parr et al. 2004; Andersen et al. 2005; Cook and Holt 2006; Silesi and Mafongoya 2006; Vasconcelos et al. 2009). However, we need to be careful how we interpret these results from a spatial point of view, because while the patches burned here were relatively small, so enabling some species to re-invade the area, the results could have been different had the burn been at a larger scale. Nevertheless, it appears that many of the species we recorded here, especially ants and spiders, but also crickets and centipedes, are able to survive a fire by using micro-refugia. A further point for consideration is that we focused only on groups with the most common species, and it may be that some very rare and threatened species may perhaps suffer catastrophic population declines in response to fire. By way of example, three Red Listed butterflies in this same geographical area have fire listed as a threat to their survival (Henning et al. 2009), yet the threatened Knysna Warbler needs the disturbance caused by fire for nesting sites (Pryke et al. 2011). Certain functional groups may also be susceptible, with detritivores at the same location here showing poor recovery in response to fire (J.S. Pryke and M.J. Samways, unpublished data). Finally, in concordance with New et al. (2010), our general knowledge of fire ecology on arthropods is still far from sufficient to be confident that we can use fire as a precision conservation management tool, and that more research, especially on spatial issues, is urgently needed in view of its importance in various ecosystems around the world.

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