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From the Editors

In addition to the research report, contributions and naturalist note that make up the bulk of this issue and, as usual, cover a range of subject areas, this number contains an index to all six issues of the journal published last year. It has been our practice over many years to provide this essential finding aid to the previous volume, and long-standing readers of *The Victorian Naturalist* will have come to expect its appearance in the April or June issue each year. One of the most remarkable features of these annual indices that might have escaped readers' notice is that, for the past 39 years, the index has been compiled singlehandedly by one FNCV member — Ken Bell.

Beginning in 1980, year by year Ken has voluntarily undertaken the laborious task of drawing the important terms and names from every published article, book review and tribute in the journal. The annual index has become an integral part of the Field Naturalists Club's holdings of its own journal. It also represents an enormous body of work, for which all researchers should be grateful. The editors are pleased to acknowledge this mammoth contribution, and express our thanks to Ken Bell.

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Registered Office: FNCV, 1 Gardenia Street, Blackburn, Victoria 3130, Australia.

Postal Address: FNCV, PO Box 13, Blackburn, Victoria 3130, Australia.

Phone +61 (03) 9877 9860;

email: admin@fncv.org.au

www.fncv.org.au

Address correspondence to:

The Editors, *The Victorian Naturalist*, PO Box 13, Blackburn, Victoria 3130, Australia.

Phone: (03) 9877 9860. Email: vicnat@fncv.org.au

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FNCV, PO Box 13, Blackburn, Victoria 3130, Australia

Phone 61 3 9877 9860. Email: admin@fncv.org.au

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Editorial Assistant: Virgil Hubregtse

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Front cover: Eastern Bearded Dragon *Pogona barbata*. Photo Chris Rehberg. See p. 53.

Back cover: *Lotus australis* var. *australis* growing in remnant grassland. Mount Cottrell. See p. 58.

Effects of time-since-fire on the invertebrate communities of Kangaroo Grass *Themeda triandra*-dominated grasslands in Melbourne, Victoria

Joel Abraham^{1,2} and John W Morgan¹

¹Department of Ecology, Environment and Evolution, La Trobe University, Bundoora, Victoria 3086

²Corresponding author. Email: joel.abraham@yale.edu

Abstract

Australia's temperate grasslands are critically endangered. Despite the instrumental role invertebrates play as consumers in these systems, grassland invertebrates are almost entirely undocumented. Similarly, the effects of fire on these invertebrates are unknown. In this study, we begin recording the invertebrate diversity of the temperate grassland ecosystem, identifying 107 species in 14 orders. We show that time-since-fire influences invertebrate richness and abundance. Richness and abundance were maximized at the most structurally-complex site, suggesting that the effect of time-since-fire is likely mediated through the structural complexity of the grass layer; increased complexity enables resource partitioning and promotes invertebrate coexistence. Thus, we suggest that intermediate burning regimes, in which grassland sites are burned every two years or so, would most benefit within-site invertebrate diversity. However, we also suggest that grasslands should be burned patchily and that variable fire regimes be implemented within a landscape to maintain the invertebrate fauna of this ecosystem. (*The Victorian Naturalist* 135 (2), 36–46)

Keywords: invertebrates, grassland, time-since-fire, resource partitioning, structural complexity

Introduction

Australia's temperate grasslands are important ecosystems, providing a range of essential services, preventing land degradation by combating erosion and reducing soil salinity (Prober and Thiele 2005). Likewise, they harbour a variety of threatened and critically endangered species, including the Striped Legless Lizard *Delma impar* and the Golden Sun Moth *Synemon plana*; these organisms are endemic to Australia's temperate grasslands (EPBC Act 2000).

Despite the importance of temperate grasslands, much about the ecology and biodiversity of these ecosystems remains unknown, which makes it difficult to implement effective conservation schemes for the preservation of the endangered organisms they harbour. The lack of information on these grasslands is, in part, because of the rarity of this ecosystem, which is among Australia's most endangered ecosystems (Carter *et al.* 2003). Australian natural temperate grasslands have declined by more than 98% from their original 2.3 million ha extent; most of the temperate grassland that remains is in patches throughout suburban areas or along railroad tracks and roadsides (Carter *et al.* 2003). The decline of natural temperate grassland in Australia is largely due to histori-

cal intensive pastoral and agricultural use of the landscape; little grassland has escaped alteration from these uses (Williams *et al.* 2005). Because of the rarity, degradation, and fragmented nature of Australian temperate grassland, various systems containing temperate grassland, including 'Natural Temperate Grassland of the Victorian Volcanic Plain', have been listed as critically endangered systems and have been protected since 2000 (EPBC Act 2000).

Their place as critically endangered systems only emphasises the need to understand Australia's temperate grasslands so that what remains can be properly conserved. However, large components of the biodiversity of these systems are undocumented, and the nuances of the dynamics that control these systems are likewise largely unknown (McMullan-Fisher *et al.* 2011). While the floristic and vertebrate communities within these systems have received attention (e.g. Tremont and McIntyre 1994; Letnic *et al.* 2004; Prober and Thiele 2005), little information is available about the invertebrate communities (Yen 1999). Invertebrates are, in general, an important but understudied element of many terrestrial ecosystems; they are an essential component of nearly every food chain (Tscharntke and Greiler 1995). This

is particularly true of grassy systems, as the invertebrates that inhabit grassy systems are particularly inconspicuous while also serving as particularly important consumers and recyclers of nutrients (Tschardt and Greiler 1995).

Australia's grasslands are unique, too, in that they are largely depauperate of large-bodied, congregating herbivorous animals, unlike those grasslands of other continents (Orlans and Milewski 2007). Thus, invertebrates serve as the primary consumers of plant material in Australian temperate grasslands, and have a potentially larger impact and importance in Australia's grasslands relative to other similar systems.

Fire is an important component of all grass-dominated systems, and Australia's temperate grasslands are no different (Daubenmire 1968). Fire is a significant and regular disturbance in these grasslands; they naturally experience frequent burns. The impact of such fires on the biodiversity of Australian temperate grasslands has been studied in recent years; different burning regimes have been shown to have variable impacts on various components of these ecosystems (Morgan 1999). Recurrent, low-intensity fires have been shown to promote the productivity of native grasses and enhance the diversity of intertussock native flora (Morgan and Lunt 1999). Recently, fire frequency (but not time-since-fire) has been shown to significantly influence fungal community composition of these systems (Egidi *et al.* 2016). The variable responses of different components of these systems to fire therefore raises the question of how these undocumented invertebrate communities might respond to different burning regimes.

In an effort to both catalogue the invertebrate diversity of these systems, as well as to understand the impacts of burning history on invertebrates, we recorded the invertebrate communities in native *Themeda triandra*-dominated grasslands that undergo regular burning within the 'Natural Temperate Grassland of the Victorian Volcanic Plain' ecosystem. The species richness and abundance of the invertebrate communities identified in these grasslands were then related to time-since-fire.

Methods

Study sites

The 'Natural Temperate Grassland of the Victorian Volcanic Plain' ecosystem is dominated by Kangaroo Grass *Themeda triandra*, a summer-growing C4 perennial grass. Melbourne, Victoria, is located at the eastern boundary of this ecosystem, and within the city there are 87 reserves that contain remnant patches of temperate grassland; these remnants are small, isolated fragments that have escaped intensive agriculture, and are thus relatively undisturbed (Morgan 1999). The underlying geology of the region is consistent across these reserves, and is characterised by tholeiitic to alkaline basalt soils formed approximately 2 million years ago (Threatened Species Scientific Committee 2008). Thus, because the geological and edaphic features were consistent across all of the reserves, the soil characteristics of the reserves were treated as consistent as well.

To determine the effects of fire regime on invertebrate community assemblage, four *T. triandra*-dominated temperate grassland sites, all located in the northern suburbs of Melbourne, were selected from within these 87 grassland reserves. Three of the sites were located in Pioneer Park (37.69°S, 144.76°E), and the other was located in the nearby Denton Avenue Park (37.76°S, 144.81°E) (Fig. 1).

These four sites have experienced variable fire histories. Site PP0 was located in Pioneer Park and was last burned on 19 April 2017; it was sampled ten days following the burn. Site PP1 was located in Pioneer Park and was last burned in 2016. Site PP2, also selected from within Pioneer Park, was burned in 2015. Site DP3, located within the Denton Avenue Park, was last burned in 2014. The fire histories of the four sites were determined in consultation with the local land manager and were verified by assessing satellite images of the sites for evidence of burning. The sites were close to each other and were sampled in consistent weather conditions, which ensured that environmental variables other than time-since-last-burned were relatively constant between the sites.

The different burning histories of the four sites meant that the grass biomass and the structure of this grass layer at each of the sites differed substantially (Fig. 2).



Fig. 1. A map of the area in which this study was undertaken, showing the two grassland reserves in which sites were established, Pioneer Park and Denton Ave Park.

Sweep net sampling

Within each of the four sites, two 50 m transects were established. The transects were 15 m apart from each other, and were likewise a minimum of 15 m away from any given edge of the site to limit edge effects.

Invertebrates were sweep netted along these transects on three consecutive days. Sampling took place from 12 April 2017 to 14 April 2017 at PP1, PP2, and DP3. PP0 was sampled first on 29 April 2017, ten days after it was burned, on 19 April 2017. The sites were sampled each day between 9 am and 2 pm. The sampling order of the two transects within each site was switched each day and the time at which sampling began was staggered. These measures were implemented to account for any variability in the invertebrate communities with time-of-day at each site. To ensure that sampling effort was consistent across all sites and transects, one sweep of the net was done per metre. Following sweep netting, the invertebrates collected in the net were transferred to a kill jar and then to

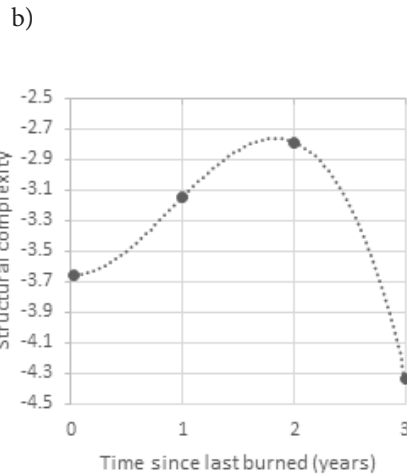
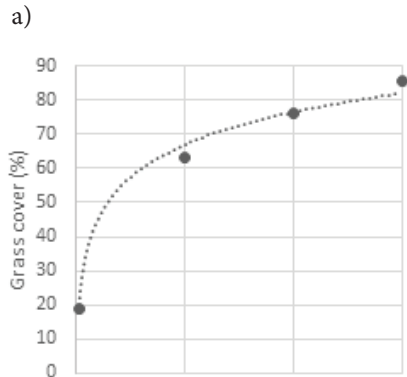


Fig. 2. The relationships between the time since a site was burned and (a) the average per cent cover of grass at that site or (b) the structural complexity of the grass layer at that site. Values for structural complexity were calculated following Brown *et al.* (2011), utilising the formula $(\ln(\text{variance in grass height} \times \text{average grass height}))$.

plastic tubes containing ethanol, for identification under a microscope.

Bee bowl sampling

Bee bowls were constructed out of white plastic bowls with a diameter of 17.5 cm and a depth of 5 cm. They were coated in florescent yellow spray paint. These bowls were placed at PP1, PP2, and DP3 on the morning of 13 April 2017, and at PP0 on the morning of 30 April

2017. They were placed along the sweep netting transects, and were spaced 5 m apart, starting at 5 m on each transect. The bowls were filled halfway with a solution of water and detergent; the detergent was added to lower the surface tension of the water so as to capture even small invertebrates. The bee bowls were placed along the transects before sweep netting took place, to ensure that any invertebrates that were disturbed during sweep netting might fall into the bee bowls. The bowls remained out for approximately 24 hours. Any invertebrates that fell into the bowls were collected and put into a plastic tube filled with ethanol for later identification.

Invertebrate identification

The invertebrates that were collected were separated into morphospecies, identified to order and assigned a unique species code. Where possible, morphospecies were identified to more specific taxonomic classifications, to the family- or genus-level. Morphospecies were also assigned to feeding guilds. Feeding guilds were classified by the system provided by Novotny *et al.* (2010) with slight modification: phloem feeders and leaf suckers were grouped into one category, 'phloem feeders'; leaf chewers and leaf mashers were likewise grouped into one category, 'leaf chewers and mashers'; and no differentiation was made between adult and larval individuals. Spiders, invertebrates of the order Araneae, were found to be particularly numerous and diverse in this study, and were thus identified to family with the aid of Frameau *et al.* (2014) and grouped based on their hunting strategies.

Grass data collection

On 29 April 2017, data on the grass layer at each of the sites were collected; the percentage of grass cover at each site as well as the average number of grass layers and the average height of each of these layers was recorded for each site. Utilising a 1 m × 1 m quadrat, 10 quadrats were randomly selected from within each site. For each of the quadrats, the percentage of the quadrat that was bare ground, rock, and covered by grass was recorded. Likewise, the number of grass layers discernable within the quadrat was recorded, as was the average height of each of these layers.

Results

Invertebrate orders

In total, 3583 individuals from 107 species in 14 orders were collected during the course of this study. Overall, Araneae was both the most abundant and diverse order; 1515 individuals were collected and were sorted into 28 different species. Diptera was the next most abundant and diverse order; 673 individuals from 23 species were collected. Collembola also constituted a substantial portion of the total individuals collected; 637 individuals were collected, though only one morphospecies was identified. Together, these three orders constituted 79% of the 3583 total individuals collected. Hemiptera, Coleoptera, and Hymenoptera were also diverse and abundant; overall, 311 individuals from 13 species, 224 individuals from 9 species, and 166 individuals from 16 species were found from these three orders, respectively. The other eight orders identified in this study—Acari, Julida, Dermaptera, Orthoptera, Lepidoptera, Gastropoda, Neuroptera and Isopoda—were rare; 15 or fewer individuals were found from each of these orders overall, and thus each of these orders constituted 1% or less of the total invertebrates found.

Overall abundances of invertebrates were similar for PP0, PP1, and DP3 (Table 1). PP2, with 1309 individuals, had nearly double the overall number of invertebrates as compared to the other three sites (Table 1). Twelve of the 14 orders were represented at PP2, the same number of orders as were found in DP3 (Table 1). PP0 and PP1, however, had members of 7 out of 14 and 11 out of 14 orders respectively (Table 1). At the species level, PP2 was most rich, followed by PP1, DP3, and then PP0 (Table 1). Seventy-four species were found at PP2, 20% of which were unique to PP2; at PP1, 13% of the 61 total species were unique; at DP3, out of the 59 species observed there 17% were unique; and PP0 had 42 species overall, 14% of which were unique (Table 1). Twenty-two species were found at all four sites. Thus, though PP2 had a slightly higher proportion of unique species, all of the sites supported a substantial proportion of unique invertebrate species.

The most diverse order at all four sites was Araneae, followed by Diptera (Table 1). The

Table 1. A comparison of the number of species in each order found at each of the four sites, along with the total number of species and the number of unique species found at each site.

Order	PP0	PP1	PP2	DP3
Acari	0	1	1	1
Coleoptera	2	5	8	5
Julida	0	0	1	1
Dermaptera	0	1	0	0
Diptera	15	12	16	13
Orthoptera	0	2	3	3
Hemiptera	3	9	7	8
Hymenoptera	5	9	11	7
Lepidoptera	1	1	3	0
Gastropoda	0	1	3	2
Neuroptera	0	0	2	1
Isopoda	0	0	0	1
Araneae	15	19	18	16
Collembola	1	1	1	1
Total SPP	42	61	74	59
Unique SPP	6	8	15	10

next two most diverse orders for PP0, PP1, and DP3 were Hymenoptera and Hemiptera, followed by Coleoptera (Table 1). At PP0, Hymenoptera was the third most diverse order, with Hemiptera as the fourth most diverse (Table 1). At DP3, this pattern was reversed, with Hemiptera more diverse than Hymenoptera, and at PP1 these orders were equally diverse (Table 1). For PP2, Hymenoptera was the third most diverse order, followed by Coleoptera and then Hemiptera (Table 1). The remaining orders were represented by three or fewer species at each site (Table 1).

PP0 and PP2 had quite similar patterns of abundance. The most abundant orders for PP0 and PP2 were the same; Araneae was most abundant followed by Diptera, Collembola, Hemiptera, Coleoptera, and Hymenoptera (Table 2). However, the abundances of all the orders at PP0 were lower than those of PP2, which was also the case at PP1 (Table 2). At PP1 the most abundant order was also Araneae, though Collembola was the second most abundant, followed by Diptera, Coleoptera, Hemiptera, and Hymenoptera (Table 2). DP3 was the most different from the other sites; Collembola was most abundant, followed by Diptera, then Hemiptera, then Araneae, then Hymenoptera, then Coleoptera (Table 2).

Table 2. A comparison of number of individuals in each order found at each of the four sites, along with the total number of individuals found at each site.

Order	PP0	PP1	PP2	DP3
Araneae	407	425	563	120
Diptera	209	63	253	148
Collembola	60	129	206	242
Hemiptera	44	44	101	122
Coleoptera	34	59	95	36
Hymenoptera	9	40	70	47
Orthoptera	0	4	6	5
Lepidoptera	3	1	4	0
Acari	0	2	4	1
Gastropoda	0	1	3	5
Julida	0	0	2	8
Neuroptera	0	0	2	1
Isopoda	0	0	0	4
Dermaptera	0	1	0	0
Total individuals	766	769	1309	739

Invertebrate feeding guilds

Six feeding guilds were delineated. At PP2, predators were most abundant, followed by omnivores, nectarivores, leaf chewers and mashers, phloem suckers, and detritivores (Table 3). At PP1, this pattern was similar, though nectarivores were the least abundant rather than the third most abundant; the order at PP1 was predators, omnivores, leaf chewers and mashers, phloem suckers, detritivores, and nectarivores (Table 3). PP0 was the next most similar; predators were again most abundant, followed by nectarivores, omnivores, phloem suckers, detritivores, and leaf chewers and mashers (Table 3). DP3, the only site for which predators were not the most abundant feeding guild, was the most different; at DP3, omnivores dominated, followed by predators, nectarivores, phloem suckers, leaf chewers and mashers, and detritivores (Table 3).

The explicit number of detritivores was comparable between the four sites (Table 3). The explicit number of omnivores increased with time-since-fire, climbing from 66 individuals at PP0 to 287 individuals at DP3 (Table 3). Predators and leaf chewers and mashers had parabolic abundance relationships; their abundances peaked at PP2 at 596 and 101 individuals, respectively (Table 3).

Similarly, the proportional abundance of detritivores did not change much between the

Table 3. A comparison of number of individuals in each feeding guild found at each of the four sites, along with the total number of individuals found at each site.

Feeding guild	PP0	PP1	PP2	DP3
Predators	417	431	596	129
Omnivores	66	167	275	287
Nectarivores	162	28	223	126
Leaf chewers and mashers	34	63	101	41
Phloem suckers	44	43	77	117
Detritivores	43	37	37	39
Total individuals	766	769	1309	739

sites, though they were at a slightly lower proportion, about 3% rather than 5%, at PP2 (Table 3). The proportion of phloem suckers was quite consistent across the first three sites at just below 6%, but they were proportionally more abundant at DP3 at about 16% (Table 3). Nectarivores were quite consistent across PP0, PP1, and DP3 at 21%, 17%, and 17% respectively; at less than 4%, PP1 showed a substantial decrease in the proportion of nectarivores collected there (Table 3). Predators were proportionally most abundant at PP1 at 56%, then PP0 at 54%, then PP2 at 46%, then dramatic decrease to DP3 at 17%. Omnivores were most prominent at DP3 at 39%, then at PP1 at 22%, then at PP2 at 21%, then at PP0 at 9% (Table 3).

Spiders

Spiders were both the most rich and most abundant order of invertebrates collected. Thus, they were investigated more closely. Twenty-eight species of spiders from 9 families were found, totaling 1515 spiders, only one of which could not be identified to family (Table 1). The vast majority of the spiders found were from one species, *Runcinia acuminata* (Thomisidae). Of this species alone 1075 individuals were found, constituting 71% of the total spiders collected. Two other species constituted another significant portion of the spiders found; 159 individuals collected were *Larinia jamberoo* (Araneidae), and another 117 individuals collected were a species from the family Lycosidae. Together, these two species comprised 18% of spiders collected. Thus, three species represented 89% of all spiders collected; the remaining 25 species constituted only 11% of all spiders collected, and were thus quite rare.

Table 4. A comparison of the number of individual spiders in each family found at each of the four sites, along with the total number of spiders found at each site.

Family	PP0	PP1	PP2	DP3
Thomisidae	381	307	354	52
Lycosidae	0	0	117	0
Araneidae	7	95	49	31
Salticidae	2	4	19	9
Oonopidae	6	6	12	7
Zodariidae	1	0	5	1
Theridiidae	9	4	4	19
Miturgidae	0	2	2	0
Oxyopidae	1	6	1	1
Unidentified	0	1	0	0
Total individuals	407	425	563	120

Fifteen species were found at PP0 from 7 families, 19 species at PP1 from 8 families, 18 species at PP2 from all 9 families, and 16 species at DP3 from 7 families (Table 4). Though PP1 was the most diverse in terms of species, PP2 was most diverse in terms of the families that were represented; PP0 and DP3 were comparably diverse in both respects.

Thomisidae was the most abundant spider family at all four sites (Table 4). At PP0, Theridiidae was the next most abundant, then Araneidae, then Oonopidae (Table 4). At PP1, the next most abundant family was Araneidae, then Oonopidae, then Oxyopidae (Table 4). At PP2, Lycosidae, then Araneidae, then Salticidae were most abundant (Table 4). At DP3, Araneidae was the second most abundant, then Theridiidae, then Salticidae (Table 4). The order of abundance for the spider families were quite distinct for all four sites, suggesting that the spider communities differed significantly over the four sites.

Spiders were further categorised by their hunting strategies. Four general hunting strategies were identified. Sit and wait ambush hunters were the most abundant at all sites (Table 5). Web prey capture hunters were the next most abundant at PP0, PP1, and DP3, followed by active hunters (Table 5). For PP2, this was reversed; active hunters were second most abundant, followed by web prey capture hunters (Table 5). Active ambusher hunters were some of the least common spiders at all sites (Table 5).

Table 5. A comparison of the number of individual spiders utilising each hunting strategy at each of the four sites, along with the total number of spiders found at each site.

Hunting strategy	PP0	PP1	PP2	DP3
Sit and wait ambushers	381	307	354	52
Active hunters	8	14	137	9
Web prey capture	16	99	53	5
Active ambushers	2	4	19	9
Unknown	0	1	0	0
Total individuals	407	425	563	120

Collection method

The two collection methods that were employed for this study, sweep netting and bee bowls, collected notably different invertebrates. Eighty-five species were collected with sweep netting, and 67 species were collected with bee bowls (Table 6). Forty of the 85 invertebrate species collected from sweep netting, 47%, were collected only by sweep netting, and 22 of the 67 species collected in bee bowls, 33%, were found only by this collection method (Table 6). Sweep netting collected more unique Araneae, Diptera, Hemiptera, Coleoptera, Lepidoptera, Gastropoda, and Neuroptera species, whereas bee bowls collected more unique Hymenoptera and Orthoptera species, and was the only method to capture Dermaptera and Isopoda (Table 6).

The two collection methods captured similar numbers of individuals; sweep netting collected 1954 individuals, and bee bowls collected 1628 individuals (Table 7). Sweep netting was much more successful at capturing Araneae, collecting 90% of the total Araneae individuals found in this study (Table 7). Sweep netting was likewise more successful at capturing Coleoptera, Hymenoptera, Julida, Orthoptera, Gastropoda, Acari, and Neuroptera (Table 7). Bee bowls were much more successful at capturing Diptera, Hemiptera, and Collembola, collecting 74%, 85%, and 99%, respectively, of the total individuals collected of these orders (Table 7). Thus, the two collection methods captured quite unique and distinct invertebrate profiles.

Discussion

This study has documented the invertebrate diversity of temperate grasslands. Before this

Table 6. A comparison of the number of species of each order collected with each of the two collection methods, sweep netting and bee bowls, employed for this study.

Order	Sweep netting	Bee bowls
Araneae	22	14
Diptera	21	13
Hemiptera	11	9
Hymenoptera	9	14
Coleoptera	9	4
Lepidoptera	3	2
Gastropoda	3	1
Orthoptera	2	4
Neuroptera	2	1
Collembola	1	1
Acari	1	1
Julida	1	1
Dermaptera	0	1
Isopoda	0	1
Total SPP	85	67
Unique SPP	40	22

Table 7. A comparison of the number of individuals of each order collected with each of the two collection methods, sweep netting and bee bowls, employed for this study.

Order	Sweep netting	Bee bowls
Araneae	1366	149
Coleoptera	218	6
Diptera	172	501
Hymenoptera	110	56
Hemiptera	47	264
Julida	8	2
Orthoptera	8	7
Gastropoda	8	1
Acari	6	1
Collembola	5	632
Lepidoptera	4	4
Neuroptera	2	1
Isopoda	0	3
Dermaptera	0	1
Total individuals	1954	1628

study, little was known about which invertebrates might be found in these landscapes (Yen 1999). One hundred and seven invertebrate species were catalogued over the course of this research project, many of which have never before been associated with these systems. Thus, this work has begun to shed light on the invertebrates that occur in Australia's temperate grasslands. Likewise, this study yielded many

surprising general findings about the invertebrates in these grasslands; the prevalence of individuals of the order Araneae was not anticipated, nor was the abundance of Collembola or Diptera.

None of these three orders explicitly consume grass biomass: the Araneae species found here are entirely predatory; Collembola are omnivorous, consuming primarily fungal hyphae, fungal spores, and pollen; and, though Diptera exhibit a wide range of feeding habits, the Diptera species identified in this study were nectarivores, detritivores, or predators. From the general abundance of predators documented in these grasslands, it would appear that the primary consumers of grass are largely eaten down by the numerous predators. These predatory invertebrates appear to be exerting top-down control on these grasslands, keeping the numbers of primary consumers low and maintaining highly productive systems (Sanders *et al.* 2008).

Beyond that, this study demonstrates the importance of structural complexity for the invertebrates of these grasslands. PP2 had the highest invertebrate abundance, nearly double that of any of the other sites. Likewise, the most invertebrate species were found at this site. PP2 was also the most structurally complex site. Increased structural complexity seems to facilitate high levels of invertebrate abundance and diversity. The most structurally simple site, DP3, featured the fewest invertebrates overall; the species diversity of this site was the second lowest, higher only than PP0.

PP0 had been burned only ten days before sampling was undertaken, and was therefore also quite structurally simple. However, in spite of this, it had a relatively high level of invertebrate abundance, nearly equal to that of PP1. The relatively high levels of invertebrate abundance and diversity despite its low overall structural complexity might be explained by the fact that the site was burned recently. Because of the burn, invertebrates were likely concentrated into fire refugia, the patches of the landscape that had escaped burning (Brennan *et al.* 2011). Furthermore, Araneae and Diptera constituted the majority of the invertebrates found at PP0, both of which are highly mobile taxa and can disperse to new habitats with ease. Thus, it is

plausible that invertebrates from these orders might have readily recolonised the site following the burn, concentrating in the portions of the site that still had structure, refugia that had survived the fire. The low overall grass cover of the site likely rendered the bee bowls more visible to invertebrates, causing them to have a higher capture rate than in the denser vegetation of the other three sites.

Indeed, previous studies on grassland systems have found structural complexity to be important for invertebrate diversity. Sanders *et al.* (2008), for example, found that habitat structure and architectural complexity strongly modified the strength of top-down forces, thereby affecting the diversity of herbivorous invertebrates; increased predator abundance had a positive effect on the diversity of herbivorous invertebrates. Their findings lend further support to the above conclusions, that structural complexity facilitates a diverse invertebrate community in these grasslands.

The likely pathway linking these two qualities, the structural complexity of these grasslands and the diversity and abundance of invertebrates, is resource partitioning; increased structural complexity likely opens up new niches that the invertebrates of these grasslands can exploit (MacArthur 1972). PP2, which had the highest abundance and diversity of invertebrates, also featured two well-developed layers of grass, with a sparse third layer. It is probable that each of the layers supported distinct invertebrate taxa, and that these layers facilitated the spatial partitioning of resources within the habitat (MacArthur 1972). The fact that the two collection methods, sweep netting and bee bowls, captured distinct invertebrates, supports the notion that different invertebrate taxa inhabited the different layers. The bee bowls were likely more successful at capturing invertebrates residing on the ground and in the lower layers of the grassland. Sweep netting, in contrast, was likely more successful at capturing the invertebrates utilising the upper grass layers. The fact that they returned distinct invertebrate profiles suggests that different invertebrates inhabit different strata of the grassland.

Further support for the notion that these grassland invertebrates partition resources spatially, which allows for higher abundance

levels of invertebrates in the more structurally complex sites, comes from the feeding guild profiles of the four sites. PP2 had a relatively low number of omnivores and higher numbers of leaf chewers and mashers. An omnivore feeding habit is less specialised, and therefore suggests a paucity of resources (Futuyma and Moreno 1988). Thus, the relative lack of omnivores suggests the opposite, that resources were abundant at PP2. Leaf chewers and mashers, by contrast, tend to be more specialised and more specific to host plants; an abundance of invertebrates of this feeding guild therefore suggests that more resources are available and, therefore, that more specific niches can be maintained (Futuyma and Moreno 1988). DP3, the structurally simplest of the four sites, had a relatively high number of omnivores. The fact that omnivores were more successful at DP3 suggests that resources were scarcer, and that only those invertebrates that can access a wider variety of food sources for their nutrition may survive.

A higher abundance and richness of herbivorous taxa, in turn, allows for a higher diversity of predatory taxa, as these predators can partition prey resources spatially (MacArthur 1972). At PP2, the tall blades of grass that formed the sparse third layer, for example, were probably ideal for web-weaving spiders, whereas the bare ground no doubt provides throughways and potential burrows for wandering spiders. Wandering spiders are active hunters, wandering over the ground searching for invertebrate prey (Framenau *et al.* 2014). Indeed, of the four sites, PP2 had by far the highest number of active hunting spiders, despite having the third-highest amount of bare ground. This may seem somewhat paradoxical. However, PP2 likely struck the balance between having sufficient bare ground for these ground spiders to move about while also having ample prey available to them. Increased structural complexity opens up more niches for herbivorous taxa, which in turn allows for spatial resource partitioning among predatory taxa, thereby increasing the overall diversity of invertebrates that can persist within the same site (MacArthur 1972).

The structural complexity that appears to be so important to the invertebrates of these grasslands is facilitated by burning. The responses

of grassland plants to fire regimes are well documented; extended periods without burning (generally intervals greater than five years without a fire) can cause inter-tussock native flora to drop out of the system due to competition with *T. triandra*, and can likewise result in a decline in the overall health of *T. triandra* due to a build-up of a substantial layer of dead thatch at the base of the tussocks (Morgan and Lunt 1999). Thus, intermediate time-since-fire maintains grassland complexity, facilitating the coexistence of other native flora with *T. triandra* while simultaneously promoting the health of this grass. This principle held true for this study; complexity steadily increased for the first few years following burning but then declined rapidly after the second year. PP2, last burned two years ago, was the most structurally complex, and DP3, last burned five years ago, was the least structurally complex. Thus, intermediate burning regimes, with controlled burns occurring about every two years or so, facilitate high levels of structural complexity in temperate grasslands, which in turn allows for a higher diversity and abundance of invertebrates. This suggests that the within-site diversity and abundance of grassland invertebrate fauna, like grassland flora, would benefit most from a burning regime with about two years between burns; such a burning regime would maximise the structural complexity of these grasslands, thereby allowing for a diverse assemblage of invertebrates to persist within a site.

However, this study demonstrates the nuance to such a suggestion. Each of the four sites possessed a substantial proportion of unique taxa not found at the other sites. Both PP0, which was just burned, and DP3, which has not been burned in five years, supported multiple unique species despite being distant from this two-year burning optimum. This suggests that, within a landscape, multiple burning regimes should be implemented; in order to maintain the whole of the invertebrate diversity within these grasslands, there must be some sites within the landscape that have short inter-burn intervals and some sites with long inter-burn intervals. Diverse fire regimes allow for a continuum of environmental characteristics such as structural

complexity and grass cover within a landscape, which in turn promotes biodiversity (Martin and Sapsis 1992). Though this study supports the notion that the distribution of burning regimes should be centred at about two years between burns, it also makes apparent that there should be some variability in the time between burns throughout a landscape so as to maintain those taxa which can survive only in longer-unburnt or more recently-burnt sites.

The results of this study demonstrate the importance of patchy burns rather than complete burns. At PPO, invertebrates were likely able to persist due to the presence of some unburnt patches within the site (Brennan *et al.* 2011). The invertebrates were likely able to recolonise the landscape from these refugia, and thereby facilitate the recovery of the local invertebrate community (Brennan *et al.* 2011). In order to ensure that grassland invertebrates can recover following a burn, burning should be patchy so refugia are available to the invertebrates.

This study served as a pilot study to assess the feasibility of implementing such an invertebrate monitoring protocol on a larger scale. The scope of this study was restricted by the amount of time available to the researchers for data collection; due to time constraints, only a handful of sites could be sampled, and so the study could not be replicated spatially. However, we are confident that the trends observed here would hold up should this study be replicated on a larger scale. Indeed, this procedure should be implemented on a wider scale throughout temperate grassland remnants, in order to get a sense of the overall invertebrate diversity these grasslands contain. Implementation of this procedure on a broader scale and continued sampling from year to year would then allow for monitoring of the invertebrate diversity of these grasslands through time.

Because sampling took place at two different grassland reserves, Pioneer Park and Denton Ave Park, some of the variation between the sites is possibly due to intersite variability; the two grassland reserves have distinct management histories, and therefore likely had slightly different invertebrate profiles to begin with. However, given the trend observed, even within Pioneer Park, of increasing diversity and

abundance with increasing structural complexity, it is possible that the observed trend is still legitimate. However, to verify this and eliminate intersite variability as a factor, this method should be replicated on a larger scale.

This study could capture only invertebrate presence in these grasslands in late autumn. Indeed, few pollinators were collected over the course of this study. Bees, specifically, which are known to be quite abundant in these grasslands, were nearly absent from the collected taxa (Batley and Hogendoorn 2009). It is likely that such pollinator taxa would be present in the spring; thus, future work should explore how the invertebrate communities of these grasslands vary seasonally. Future work should also attempt to definitively identify the 107 invertebrate species collected in this study, as well as those found in future studies, to the species level, so as to begin the process of compiling a comprehensive profile of the biodiversity of this system. As both collection methods employed in this study captured distinct invertebrate profiles, both methods should be employed to assess invertebrate presence in future studies of this nature.

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