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Long term effect of fire, flood and grazing on invertebrates in Australia's arid zone: Collembola and Formicidae

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Abstract

An extensive fire followed almost immediately by a large scale flood occurred in the semi-arid/arid Olary Creek area in southwest New South Wales. In order to monitor the short and long term effect of these extreme events on vegetation, replicate paired plots were established in the flooded, burnt, and both flooded and burnt landscapes. The plots were 25 m square and one pair of each plot was fenced to exclude grazing animals. We report here on the long-term effect of this disturbance on terrestrial and arboreal invertebrates thirteen years after the events, using Formicidae and Collembola as exemplars. Our results showed that abundance and species richness of both Formicidae and Collembola were more affected by vegetation on the plots and only indirectly by impacts, while the vegetation was determined by the impact history on different land units. Perennial native grasses were favoured by the flooding and rainfall resulting in a high abundance of species in the genus *Corynephoria* (Collembola: Symphypleona) mainly on swales, while Formicidae species were trapped in highest numbers where the dune vegetation of hummock grassland (*Triodia scariosa*) was abundant on control plots and plots affected by fire. Grazing had little effect on these invertebrates. These results suggest that optimal management of invertebrate biodiversity in the region needs a mosaic of strategies with both fire and flood providing benefits.

Keywords: Acacia, ants, native grasses, pitfall traps, springtails, sweep samples, *Triodia*

1. Introduction

Invertebrates are, at times, extremely abundant in Australia's arid zone despite the severity of the environment and associated extremes in climatic conditions. Within this environment generally the most abundant ground-active taxa are the Formicidae following by Acarina and Collembola (Greenslade & Greenslade 1984) with Isoptera and Orthoptera also abundant but more sporadic in occurrence. The dominant taxa of these arid areas show markedly differing behavioural traits that often contribute to their distribution and occurrence. For instance, many Formicidae are able to be active in dry conditions and even at the hottest time of the day while Collembola are found at their most abundant in moist conditions often after seasonal rainfall events (Greenslade & Greenslade 1984). These groups play a major role in ecosystem processes, including decomposition of organic matter and soil formation, and, as a consequence, it is essential to understand influences on their abundance and species composition. Disturbance both frequent, in the form of grazing and seasonal rainfall and infrequent, fire and flood, have the potential to drastically alter the existing landscape and significantly effect the biodiversity of these arid ecosystems. Although several studies have published on the effect of fire, grazing and rainfall on semi-arid/arid zone invertebrates (Greenslade & Mott 1983, Gunawardene & Majer 2005, Morton et al. 2011), the effect of floods of long duration has not be examined in arid landscapes.

Similarly, although the topic has been studied in more detail in European temperate climates (Lessel et al. 2011), little is known about arid ground faunas recovering after flooding in Australia although data on short term effects of flood on ants in the Murray Valley has recently been published (Horrocks et al. 2012). A little more is known of the effect of grazing in the arid zone on invertebrates (Greenslade 1993, Read & Andersen 2000) but the only data on the combined and separate effect of fire and grazing is from the non-arid White Box grassy woodlands (Prober et al. 2007, Greenslade 1997); climate information on the effect of grazing on invertebrates in a more humid has been reported by several authors (King et al. 1985) but the combined effect of fire, flooding and grazing on invertebrates, has not been studied in the arid zone landscape systems of Australia before.

Extreme weather events are always unpredictable and uncommon especially in the Australian arid zone, but predicted to become more frequent (Rahmstorf & Coumou 2011). Consequently, when an extensive fire followed almost immediately by an extensive flood occurred in the semi-arid/arid Olary Creek area adjacent to the Nanya research station of the University of Ballarat, advantage was taken of these events to examine effects. Plots were established so that long term effects of a flood, fire and grazing and their interactions had on vegetation structure could be examined (Westbrooke et al. 2005). In the current study, we investigated the possible long-term effect of this disturbance on terrestrial and arboreal invertebrates, using Formicidae and Collembola as exemplars, thirteen years later.

2. Study sites

The study site is located in the southern portion of Nagaela Station, south-western New South Wales which is lightly stocked with cattle and goats. The location is 22 km NNW of the homestead at University of Ballarat's field Research station at Nanya, which is managed for conservation, education and research. Kangaroos are present in low numbers. A major flood occurred along the Olary Creek running diagonally south-east across Nagaela in February 1997 and formed an extensive temporary lake to a depth of approximately 2 m that remained for over a year (Fig. 1). Two months prior to the flood event in December 1996 a substantial part of the future flooded and adjacent unflooded area was burnt in a wild fire. Flood and fire chronology and subsequent research are further detailed in Westbrooke et al. (2005), Florentine & Westbrooke (2005) and Florentine et al. (2006). The broad land system of the study area is generally dune fields consisting of low parallel ridges and swales running east-west composed of red earthy sands and sandy solonised brown soils overlying sandy clays (Walker 1991). The vegetation of the study area prior to the flood and fire was typical Scotia mallee dominated by Yorrell (*Eucalyptus gracilis*), Dumosa Mallee (*E. dumosa*) and Grey Mallee (*E. socialis*) with an understory consisting of hummock grassland (*Triodia scariosa*).

Study plots were originally established in February 1999 to monitor the relative vegetation change post disturbance and the influence of herbivore grazing on the recovery of either flooded, or burnt or flooded and burnt sites. Paired 625 m^2 (25 × 25 m) plots were set up under

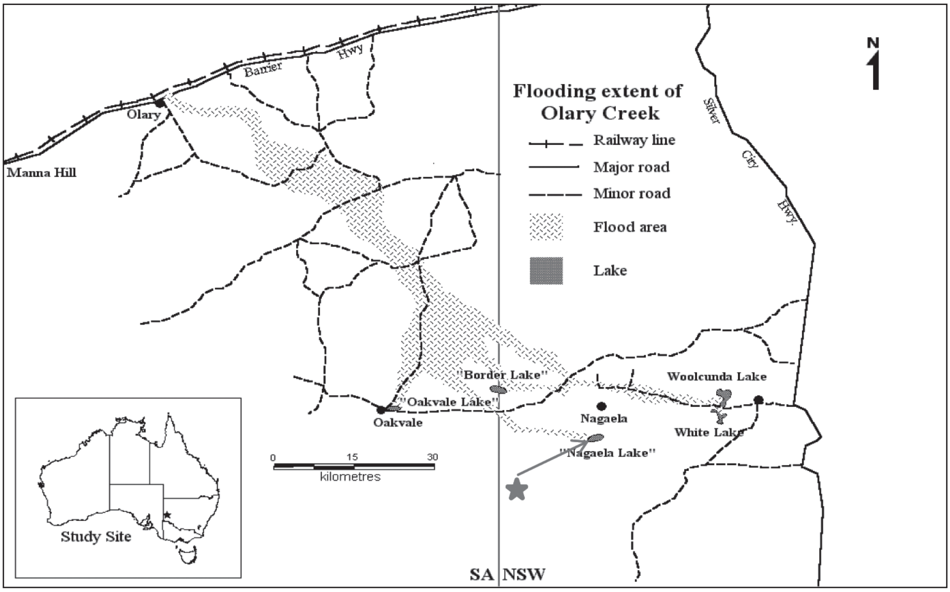

Fig. 1 Location of Olary Creek and extent of 1997 flood. Location of wildfire marked with arrow.

four disturbance 'treatments': (i) not flooded, unburnt; (ii) flooded, unburnt; (iii) not flooded, burnt and (iv) flooded, burnt. One plot in at each treatment site was left unfenced while the other was fenced to exclude grazing by both introduced and native animals. The fence was constructed of 150 mm wire mesh to a height of 1.7 m. Two replicates of each treatment were established giving 16 plots in all which are listed in table 1 together with each plot's treatment. Plots 3 and 4 were located in a swale, plots 5 and 6 about 200 m away over a low dune and on more sandy soil (Tab. 1.). Plots 7 and 8 were located 5 km away on a dune which had formed as a result of the flood and 9 and 10 on an established dune (Tab. 1, Fig. 1). Plot description, monitoring effort and habitat data up to 2006, are described by Westbrooke et al. (2005), Florentine & Westbrooke (2005) and Florentine et al. (2006).

The annual rainfall for the region is approximately 250 mm, with high annual variability (BOM 2005). The climate is classified as cool semi-arid although rainfall of 250 mm can be classified as arid. It is, characterised by high summer temperatures (February mean daily max = 32°C, min = 16°C) and mild winters (July mean daily max = 15°C, min = 5°C) (BOM 2005). At the time of sampling, April 14th to 17th 2012, the weather was warm to hot with a mean maximum temperature of 30.3°C and minimum of 8.9°C recorded at the Nanya homestead. Although only 0.4 mm rain fell during the 13 days prior to sampling, 31.8 mm fell in March, two months before sampling but only 1.6 mm in February.

3. Methods

Invertebrates were sampled using pitfall traps (Greenslade & Greenslade 1971) and although they are biased against more cryptic and arboreal species (Greenslade 1975) these species were not thought to occur in substantial numbers in the study area. Five small pitfall traps, 1.8 cm in diameter, 8.5 cm deep three quarters filled with 95 % alcohol with a few

Tab. 1 Details of fire and flood sites, sampling conducted and biotic and abiotic characteristics.

Plot Number	fenced	Fire	Flood	Coordinates	Leaf litter		Altitude
3	Y	N	Y	33° 02.099' S, 141° 12.968' E	dead grass only	WP 109, dead mallee, Nicotinia present, all much grass, *Aristida*, *Eragristis*, *Stipa*, *Danthonia*	50 m
3	N	N	Y	33° 02.099' S, 141° 12.968' E	dead grass only	Less grass	50 m
4	Y	Y	Y	33° 02.099' S, 141° 12.968' E	dead grass only under mallee	1 large mallee, 2 pf under mallee, others under grass	50 m
4	N	Y	Y	33° 02.099' S, 141° 12.968' E	dead grass only	no mallee, *Senna*, *Acacia*, *Triodia*, *Maireana*, *Sclerolaena*, *Duboisia*	50 m
5	Y	Y	N	33° 02.400' S, 141° 12.922' E	under mallee only	WP 110, much mallee, *Triodia*	71 m
5	N	Y	N	33° 02.400' S, 141° 12.922' E	under mallee only	As for fenced 5 but less *Triodia*, less dense	71 m
6	Y	N	N	33° 02.400' S, 141° 12.922' E	under mallee only	Dense mallee, *Triodia*, otherwise open sand	
6	N	N	N	33° 02.400' S, 141° 12.922' E	under mallee only	As for fenced 6, plant species richness low	
7	Y	N	Y	33° 01.813' S, 141° 12.365' E	50%	WP 111 Many tall shrubs (*Acacia*), with mallee, leaf litter under shrubs	58 m
7	N	N	Y	33° 01.813' S, 141° 12.365' E	trace	No shrubs stags, just dead grass, 40% *Stipa*, rather sparse	58 m
8	Y	Y	Y	33° 01.813' S, 141° 12.365' E	under shrubs 90%	very very dense *Acacia*, canopy nearly 100%,	58 m
8	N	Y	Y	33° 01.813' S, 141° 12.365' E		dead *Stipa* only	58 m
9	Y	N	N	33° 01.629' S, 141° 12.022' E	70%	WP 112, total mallee cover, 2 spp *Eremophila*, *Sclerolaena*, and other spp.	56 m
9	N	N	N	33° 01.629' S, 141° 12.022' E	under mallee	Fewer shrubs, only mallee and *Triodia*, less leaf litter	56 m
10	Y	Y	N	33° 01.629' S, 141° 12.022' E	10%	small mallee, *Triodia* tall, sand 50%	56 m
10	N	Y	N	33° 01.629' S, 141° 12.022' E	under mallee	Mallee, smaller *Triodia*, more grass, *Stipa*	56 m

drops of glycerol to prevent evaporation were placed, flush with the ground surface, at 2 m intervals in a line in the centre of each of the 16 plots. Surrounding ground was cleared to 15 cms diameter and the pitfall traps were left open for 4 days (Tab. 1).

To sample for invertebrates on vegetation, a series of timed vegetation sweeps were made (50 double paces, i.e. 100 180° sweeps) with a fine linen net, diameter approximately 50 cms within each plot. Samples from both collection methods were stored in 95 % alcohol. Invertebrate samples were identified to morphospecies and, where possible, to species using to taxonomic keys for Formicidae genera (Shattuck & Barnett 2001) and Collembola (Greenslade unpublished).

Photographs were taken of each of the plots, notes made on the vegetation and coverage of ground leaf litter and the coordinates recorded. All soils appeared predominately sandy with a very sparse stone cover. There was some fallen dead timber on the ground of all plots but it varied as to the amount.

4. Data analysis

The use of abundance and species richness of ants as parameters for analysis can be misleading when small data sets are used (Greenslade 1979, Gunawardene & Majer 2005). As a consequence, the species record for each pitfall was transformed into frequency data by converting the number of traps on each plot in which any species occurred to five if the species occurred in each pitfall on a plot to zero if the species was not recorded from any of the five pitfalls (Tab. 4).

We used the ant untransformed frequency data for the analysis (Tab. 4). Data were analysed using Primer 6© (Primer-E, Ltd, Luton, U.K.) (multivariate analysis). Differences in species frequency between sites were assessed using the 3-way PERMANOVA on treatment crossed with fencing based on the Bray–Curtis similarity. In the 3-way PERMANOVA design with the following factors: Treatment: fixed factor 4 levels (Fire/Flood/FiFl/Con); Fencing: fixed factor 2 levels (Fenced/Open) and Plot: random factor nested in Treatment (but crossed with Fencing), 2 plots for each treatment. An MDS plot was used to assist with the interpretation. Simple linear correlations were performed using STATGRAPHICS® Centurion XVI software package to determine the type of association between *Corynephoria* numbers and native grass cover. Equitability (evenness) of each plot was also calculated using abundance data of each ant species.

As collembolan collections from the sweeps consisted almost entirely of *Corynephoria* species, absolute numbers of total Collembola per plot were to calculate a correlation against native grass cover measured two months earlier on each plot and Analysis of Variance also calculated using the same data. Too few Collembola were collected in pitfalls for analysis, the same was true for ants from sweeps.

5. Results

5. 1. Sweeps

The fauna collected from the sweep samples are summarised in table 2 and given in full in Appendix 1. Among the nearly 500 individuals caught, the most abundant taxa collected were Collembola belonging to the genus, *Corynephoria*, an abundant and diverse genus in Australia's arid zone (Tab. 2). Four species were collected. The next most abundant group were spiders (8 % of catch). All other groups such as, Thysanoptera, Formicidae, other

Hymenoptera and oribatid mites comprised less than 5 % of the total catch. The flooded plots had most taxa, including *Corynephoria*, with individuals being rather more numerous in the fenced plots than unfenced plots. Plots that were only burnt and control plots had fewer species and other taxa.

5.2. Pitfalls

The total number of invertebrates caught (Tab. 3, Appendix 2) comprised 15 invertebrate orders and 30 higher taxa. Over 99 % of individuals were ants and there were 621 other individuals. Diptera were fairly abundant at 146 individuals but most belonged to a single species that was probably attracted to the preservative, particularly the glycerol, in traps.

Tab. 2 Summary of fauna collected by sweep samples from Nagaela flood and fire monitoring plots, April 2012.

Taxa		**Plots**																
		Flood		**Flood & Fire**		**Fire**		**Control**		**Flood**		**Flood & Fire**		**Fire**		**Control**		
Class	**Species**	**3 fenced**	**3 unfenced**	**4 fenced**	**4 unfenced**	**5 fenced**	**5 unfenced**	**6 fenced**	**6 unfenced**	**7 fenced**	**7 unfenced**	**8 fenced**	**8 unfenced**	**9 fenced**	**9 unfenced**	**10 fenced**	**10 unfenced**	**Total**
Collembola	*Corynephoria* species (Symphypleona)	56	36	31	36	1		3	4	10	37	2	41	12	11		1	**281**
Collembola	Other Collembola	3																**3**
Insecta		19	9	6	5	8	2	3	1	10	9	36	8	8	3	14	2	**143**
Arachnida	Araneae	8	3	6	5	1	8	5	8	2	3		1	3	4	10	3	**70**
	Totals	**86**	**48**	**43**	**46**	**10**	**10**	**11**	**13**	**22**	**49**	**38**	**50**	**23**	**18**	**24**	**6**	**497**
	No. of taxa	**14**	**9**	**12**	**8**	**5**	**4**	**6**	**4**	**6**	**7**	**8**	**6**	**11**	**6**	**7**	**5**	

Tab. 3 Summary of pitfall catches on plots at Nagaela Station.

		3 fenced	**3 unfenced**	**4 fenced**	**4 unfenced**	**5 fenced**	**5 unfenced**	**6 fenced**	**6 unfenced**	**7 fenced**	**7 unfenced**	**8 fenced**	**8 unfenced**	**9 fenced**	**9 unfenced**	**10 fenced**	**10 unfenced**	**Totals**
Coll.	Symphypleona	6	7	2	4	2	0	3	1	0	3	0	11	0	4	1	0	**44**
Coll.	*Drepanura cinquilineata*	10	16	17	12	2	3	0	0	3	47	1	26	0	0	0	2	**139**
Coll.	*Acanthurella halei*	6	4	2	1	0	8	1	1	1	0	0	0	7	8	10	3	**52**
Coll.	Immmature Entomobryidae	1	5	9	1	0	8	1	1	1	0	0	5	7	8	10	3	**60**
Insecta	Other	18	54	10	17	19	26	7	12	20	8	9	8	13	0	23	9	**253**
Insecta	Formicidae	288	152	179	160	88	50	418	74	110127	334	910	698	46	5156	87	223	**118990**
Arach.		1	6	4	0	0	2	2	5	0	0	0	1	12	0	25	14	**72**
Total		**330**	**244**	**223**	**195**	**111**	**97**	**432**	**94**	**110152**	**392**	**920**	**749**	**85**	**5176**	**156**	**254**	**119610**

Fifty one species of ants were distinguished from nearly 12,000 individuals but they were strongly aggregated with large numbers trapped close to nests. For instance highest abundance was found on fenced plots 7 and 8 where abundant low shrubs of *Acacia rigens* and *Acacia colletioides* were present as well as extensive leaf litter. Control plot 9 also had high numbers because of proximity of nests to traps. The most abundant group after ants were the Collembola with 285 individuals and six species. Most of the Collembola species belonged to the species *Drepanura cinquileata* Womersley while *Corynephoria* individuals were few and sporadic in distribution (Tab. 3).

Our results from the ANOVA on the frequency ant data, show that there is a significant plot effect (Tabs 5, 6), but no significant effect of treatment or fencing (or Treatment x Fencing interaction) effects. This is clear also when we average across the two plots in each treatment, but kept the fenced and unfenced samples unaveraged. The MDS from this averaged plot shows more of a Flood *vs* non-Flood difference rather than the four combinations of treatments (Fig. 2). Based on this results the PERMANOVA for (Fire: yes or no, Flood: yes or no, fencing: yes or no, Plot) was calculated. In this analysis, plot is now nested in both Flood and Fire (Tabs 5, 6).

The results for Collembola differ (Fig. 3, Tabs 7a, b). The output shows the results of fitting a linear model to describe the relationship between *Corynephoria* numbers caught by sweeping and native grass cover. The equation of the fitted model is: *Corynephoria* numbers = 3.88215 + 0.83973* native grass cover. Since the P-value in the ANOVA table is less than 0.05 at 0.0000, there is a statistically significant relationship between *Corynephoria* numbers and native grass cover at the 95.0% confidence level. The R-Squared statistic indicates that the model as fitted explains 91.5037% of the variability in *Corynephoria* numbers. The correlation coefficient equals 0.956576, indicating a relatively strong relationship between the variables. The standard error of the estimate shows the standard deviation of the residuals to be 5.62299. This value can be used to construct prediction limits for new observations by selecting the Forecasts option from the text menu (Fig. 3). The mean absolute error (MAE) of 3.89309 is the average value of the residuals. The Durbin-Watson (DW) statistic tests the residuals to determine if there is any significant correlation based on the order in which they occur in your data file. Since the P-value is greater than 0.05, there is no indication of serial autocorrelation in the residuals at the 95.0% confidence level (Fig. 3).

Equitability of each plot for ants is shown in table 8. Although one control unfenced (6), in a dune dominated by mallee and *Trodia* has highest equitability and there is some indication that fire rather than flood promote a more even fauna as the data indicates that ant faunas are more equable on the first, interdune replicate plots (3, 4) and least on the second (dune) replicate plots (1, 8) (Tab. 8).

6. Discussion

The results for the two taxa, Formicidae and Collembola differ in that ant assemblages show no long term impacts of fire, flood and grazing separately or combined while Collembola appeared to positively respond to flood. *Triodia scariosa* dominated dune sites but was nearly absent from swales. Species richness of ants was highest on *Triodia* (dune) dominate plots (5, 6, 9, 10) with some negative effect of grazing on plots 9 and 10. Equitability was also highest on some *Triodia* dominated plots (5, 6) but also fire seemed to have some influence (plots 4). Although any conclusions from the analysis on ant fauna must be qualified as only pitfall traps were used as a collecting method, we did not consider digging in effects for practical reasons and samples were only taken once and under dry conditions. Even so, our results are in agreement with those of other authors when using pitfalls in the arid zone as a sole method.

Although the effect of fire on ant assemblages can be variable, several studies have recorded higher abundances and species richness in burned areas than unburned areas (York 1994) while others have revealed either altered species compositions (York 2000) or no significant effect caused by fire (Hoffman 2003).

Tab. 4 Frequency of Formicidae species collected from five pitfall traps on each plot April 2012. Abbreviations.: gr. = group, nr. = near.

		3 fenced	3 unfenced	4 fenced	4 unfenced	5 fenced	5 unfenced	6 fenced	6 unfenced	7 fenced	7 unfenced	8 fenced	8 unfenced	9 fenced	9 unfenced	10 fenced	10 unfenced
		Frequency															
		Flood only		Fire & Flood		Fire only		Control		Fire		Fire & Flood		Control		Fire only	
1	*Iridomyrmex* sp. A	**4**	5	**5**	2	**0**	1	**5**	0	**5**	5	**5**	5	**5**	5	**4**	5
2	*Monomorium* sp. A	**4**	4	**2**	4	**0**	2	**1**	2	**0**	2	**0**	1	**0**	2	**0**	0
3	*Monomorium* sp. B	**4**	5	**3**	4	**2**	4	**1**	3	**0**	0	**0**	0	**2**	2	**0**	4
4	*Pheidole rugosula*?	**5**	2	**3**	2	**1**	0	**2**	2	**0**	0	**0**	0	**0**	0	**0**	0
5	*Iridomyrmex* sp. C	**0**	1	**3**	5	**0**	3	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0
6	*Melophorus* sp. A	**4**	0	**2**	0	**1**	2	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0
7	*Tetramorium* (*impressum* gp.)?	**3**	0	**0**	1	**0**	1	**0**	0	**0**	0	**0**	0	**2**	0	**0**	0
8	*Melophorus* sp. B	**1**	0	**1**	0	**0**	0	**0**	0	**0**	0	**0**	0	**0**	1	**0**	0
9	*Iridomyrmex* sp. B	**2**	0	**2**	2	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0
10	*Iridomyrmex* sp. nr. *brunneus*?	**0**	0	**5**	3	**3**	0	**1**	0	**0**	0	**0**	0	**0**	0	**0**	0
11	*Anonychomyrma* sp. A	**0**	0	**0**	2	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0
12	*Monomorium* sp. C	**0**	0	**0**	0	**0**	1	**0**	0	**0**	0	**0**	0	**0**	1	**0**	0
13	*Camponotus aranetus*	**0**	0	**0**	1	**0**	0	**0**	0	**0**	0	**0**	0	**0**	2	**3**	0
14	*Melophorus* sp. C	**0**	0	**0**	1	**0**	0	**1**	0	**0**	0	**3**	0	**0**	0	**0**	0
15	*Iridomyrmex* sp. D	**0**	0	**0**	1	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0
16	*Solenopsis* sp. A	**0**	0	**0**	1	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0
17	*Rhytidoponera* sp. A	**0**	0	**0**	1	**0**	0	**3**	3	**0**	0	**0**	0	**0**	0	**0**	0
18	*Camponotus clarion*	**0**	0	**0**	0	**0**	0	**0**	1	**0**	0	**0**	0	**0**	1	**0**	0
19	*Camponotus* sp. A	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0
20	*Rhytidoponera* sp. B	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0	**0**	1

21	*Tapinoma* sp. A (*minutum* gp.)	**0**	0	**0**	0	**0**	1	**0**	0	**0**	0	**1**	0	**0**	0	**0**	0
22	*Camponotus armstrongi*	**0**	0	**0**	0	**0**	2	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0
23	*Crematogaster* sp. A	**0**	0	**0**	0	**2**	2	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0
24	*Technomyrmex* sp. A	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0	**1**	0
25	*Iridomyrmex* sp. nr. *hartmeyeri*?	**0**	0	**0**	0	**0**	2	**1**	0	**0**	0	**0**	0	**0**	0	**0**	0
26	*Melophorus* sp. D	**0**	0	**0**	0	**0**	2	**0**	0	**0**	0	**0**	0	**0**	3	**0**	0
27	*Camponotus leae*	**0**	0	**0**	0	**1**	0	**0**	0	**0**	0	**0**	0	**0**	0	**0**	1
28	*Rhytidoponera metallica*?	**0**	0	**0**	0	**1**	0	**0**	1	**0**	0	**0**	0	**0**	0	**0**	0
29	*Polyrhachis* sp. A	**0**	0	**0**	0	**1**	0	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0
30	*Melophorus* sp. E	**0**	0	**0**	0	**1**	0	**0**	0	**0**	0	**0**	0	**0**	0	**0**	1
31	*Melophorus* sp. F	**0**	0	**0**	0	**1**	0	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0
32	*Stigmacros* sp. nr. *barretti*?	**0**	0	**0**	0	**1**	0	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0
33	*Pachycondyle* sp. A	**0**	0	**0**	0	**1**	0	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0
34	*Nylanderia* sp. A	**0**	0	**0**	0	**0**	0	**0**	2	**0**	0	**0**	0	**0**	0	**0**	0
35	*Iridomyrmex brunneus*?	**0**	0	**0**	0	**0**	0	**0**	4	**0**	0	**0**	0	**0**	0	**0**	0
36	*Meranoplus* sp. A	**0**	0	**0**	0	**0**	0	**1**	2	**0**	0	**0**	0	**0**	0	**0**	0
37	*Melophorus* sp. G	**0**	0	**0**	0	**0**	0	**0**	2	**0**	0	**0**	0	**0**	0	**0**	0
38	*Solenopsis* sp. A	**0**	0	**0**	0	**0**	0	**0**	1	**0**	0	**0**	0	**0**	0	**0**	0
39	*Camponotus gibbonotus*	**0**	0	**1**	0	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0
40	*Monomorium* sp. D	**0**	0	**0**	0	**0**	0	**0**	1	**0**	0	**0**	0	**0**	0	**0**	0
41	*Melophorus* sp. H	**0**	0	**0**	0	**0**	0	**0**	1	**0**	0	**0**	0	**0**	0	**0**	0
42	*Ochetellus* sp. (*glaber* gp.)	**0**	0	**0**	0	**0**	0	**1**	0	**0**	0	**0**	0	**0**	0	**0**	0
43	*Tetramorium* sp. A	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0	**0**	1	**3**	2
44	*Iridomyrmex* sp. E	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0	**0**	1	**0**	0
45	*Doleromyrma* sp. (*darwiniana* gp.)	**0**	0	**0**	0	**1**	0	**2**	0	**0**	0	**0**	0	**0**	3	**0**	1
46	*Tetromorium* sp. B	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0	**0**	1	**0**	0
47	*Camponotus capito*	**0**	0	**0**	0	**0**	1	**0**	0	**0**	0	**0**	0	**1**	1	**0**	1
48	*Camponotus* sp. B	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0	**0**	1	**0**	0
49	*Calomyrmex purpureus*	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0	**1**	0	**0**	1
50	*Camponotus tricoloratus*	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0	**1**	0	**1**	0
51	*Camponotus* sp. C	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0	**0**	0	**1**	1
	Total records	**27**	17	**27**	30	**17**	24	**19**	**25**	**5**	**7**	**9**	**6**	**12**	**25**	**13**	**18**
	Number of species per plot	**8**	5	**10**	14	**12**	13	**11**	**13**	**1**	**2**	**3**	**2**	**6**	**13**	**6**	**10**

Tab. 5 Three-way PERMANOVA of variance for the Formicidae species frequencies collected from Nagaela, NSW.

Source	df	SS	MS	Pseudo-F	P(perm)	perms
Flood/Fire/Control	3	6432.5	2144.2	0.58824	0.7854	105
Open/Fenced	1	939.99	939.99	0.79016	0.5353	9839
Plot (Flood/Fire/Control)	4	14580	3645.1	3.0641	**0.0176**	9936
Flood/Fire/ ControlxOpen/Fenced	3	2364	788	0.6624	0.8138	9921
Res	4	4758.4	1189.6			
Total	**15**	**29075**				

Significant differences: at p < 0. 05

Tab. 6 Three-way PERMANOVA of variance for the Formicidae species frequencies collected from Nagaela, NSW.

Source	df	SS	MS	Pseudo-F	P(perm)	perms
Flood	1	3027.4	3027.4	0.83055	0.5274	270
Fire	1	1916.5	1916.5	0.52579	0.6948	269
Fence	1	939.99	939.99	0.79016	0.5469	9837
FloodxFire	1	1488.6	1488.6	0.40838	0.7587	270
FloodxFence	1	883.64	883.64	0.7428	0.5677	9835
FirexFence	1	575.46	575.46	0.48374	0.7452	9830
Plot (FloodxFire)	4	14580	3645.1	3.0641	**0.0161**	9949
FloodxFirexFence	1	904.89	904.89	0.76066	0.5546	9831
Res	4	4758.4	1189.6			
Total	**15**	**29075**				

Significant differences: at p < 0. 05

Tab. 7a Coefficients and probability of abundance of *Corynephoria* species in sweep samples against abundance of native grasses.

Parameter	Least Squares Estimate	Standard Error	T Statistic	P-Value
Intercept	3.88215	1.7874	2.17196	0.0475
Slope	0.83973	0.0683867	12.2791	0.0000

Tab. 7b Analysis of Variance of frequency of *Corynephoria* species in sweep samples against abundance of native grasses.

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	4767.29	1	4767.29	150.78	0.0000
Residual	442.652	14	31.618		
Total (Corr.)	**5209.94**	**15**			

Correlation Coefficient = 0.956576, R-squared = 91.5037 percent, R-squared (adjusted for d.f.) = 90.8968 percent, Standard Error of Est. = 5.62299, Mean absolute error = 3.89309, Durbin-Watson statistic = 2.28679 (P=0.6818), Lag 1 residual autocorrelation = -0.148267

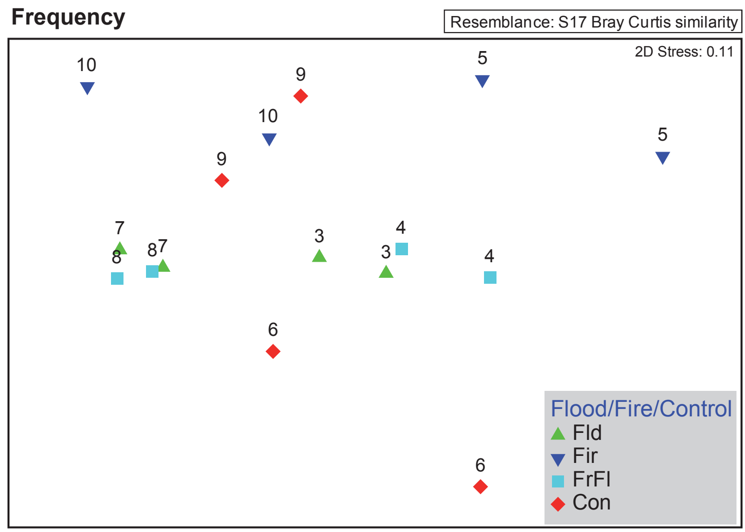

Fig. 2 MDS of ant frequency data from each plot with stress value of 0.011. Fld = flood affected plots, Fir = fire affected plots, FrFl = both fire and flood affected plots, Con = control. Plots are clustered according to land unit and vegetation and not according to impact except for sites 5 (burnt) and 6 (control) which had more *Triodia* than the other plots. There are negligible differences between grazed and ungrazed plots except for plots 5 and 6. Plots 3 and 4 were adjacent in swales; 7 and 8 adjacent on new sand dune and 9 and 10 adjacent on an old sand dune.

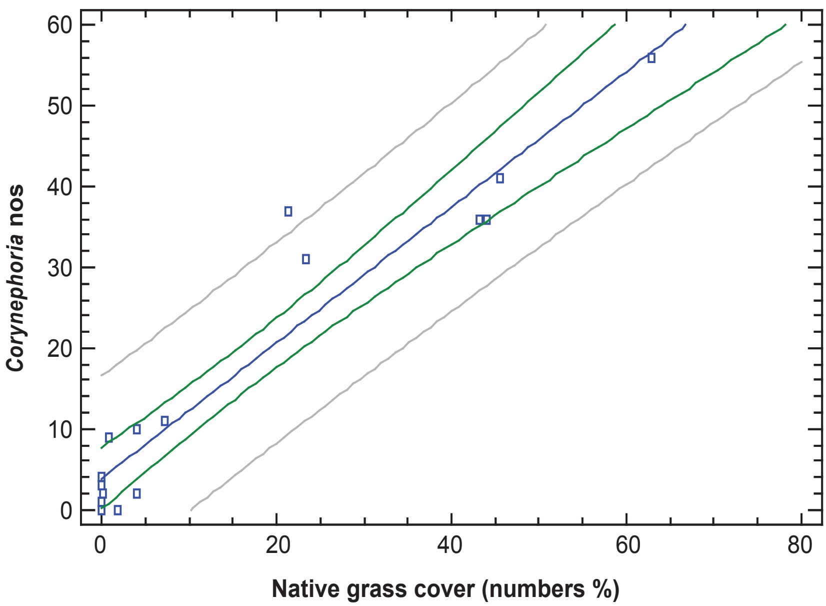

Fig. 3 The relationship between *Corynephoria* abundance and percentage native grass cover on each plot.

Tab. 8 Summary of evenness of Formicidae species on each plot with F = a fenced plot and UF = an unfenced plot. Greyed data indicate dune (second) replicate plots.

Plot	**value**	
UF6	2.24231	Control
UF5	2.04291	Fire
F5	1.89692	Fire
F4	1.87327	Fire Flood
UF4	1.44902	Fire Flood
F3	1.41696	Flood
F9	1.29072	Control
UF3	1.00346	Flood
F10	0.38804	Fire
F6	0.3686	Control
UF9	0.32531	Control
UF10	0.27845	Fire
F8	0.07738	Fire Flood
UF7	0.07303	Flood
UF8	0.05407	Fire Flood
F7	0	Flood

Our results showed that ants were most species rich on the two *Triodia scariosa* dominated plots irrespective of fire history (Tab. 2, Fig. 2, sites 5, 6, 9, 10), suggesting that vegetation structure plays an important role in determining ant assemblages in arid environments. Gunawardene & Majer (2005) sampled recent and long unburnt sites in arid Western Australia and similarly found significant positive correlation between ant species composition and percentage cover of live and dead *Triodia scariosa.*

Two sites in our study (7, 8), which were on dunes at the edge of the earlier flooded area revealed very high numbers of a species of *Iridomyrmex* which is thought to be in response to the high density of *Acacia rigens* (Needle Wattle). Propagules of this shrub probably floated to the water´s edge floated onto this area and germinated once the flood had retreated. *Acacia rigens* produces seeds with elaiosomes that are a known food resource for ants. Paired sites that were not fenced to exclude grazing had no acacias and had far few ants suggesting a strong correlation between the shrub and *Iridomyrmex* sp. Apart from this effect, ant assemblages showed no significant response to flood suggesting that the length of time since the flooding, and the resultant floristic regeneration on site, could have mitigated any short-term negative impact the inundation may have had. Horrocks et al. (2012) study of flooding effects along the Murry River showed a marked increase in activity and species composition of ant faunas but their work was in the extreme short term.

Ant response to grazing has been shown to vary widely across landscapes. In a similar result to Read & Andersen (2000) who studied the impact of cattle grazing at various intensities in the arid zone, the overall effect of grazing on ant communities in our study was not significant except where acacias were abundance as noted above.

With Collembola we found a highly significant relationship between cover of native grasses and Collembola abundance. This is of importance because it shows that even using a semi–quantitative method such as a standard sweep, quantitative data can be obtained. Greenslade & Greenslade (1984) showed a qualitative relationship between native grasses and *Corynephoria* in the arid zone but this has now been supported statistically here. We did not find a negative response to grazing although it may be present as a visual assessment showed that native grass was taller in fenced compared to unfenced plots. Frequent fire was shown by Greenslade & Mott (1983) to have a negative effect on Collembola abundance and species richness collected by suction and soil samples in a semi–arid/arid pasture but native grass abundance was not measured in this study and many more taxa of Collembola (51) were involved. As a result of its effect on vegetation, in this case native grass cover, flood enhances the collembolan fauna while grazing and fire impacts it negatively but this response is entirely dependent on type of vegetative cover. However, we suspect that the effective rainfall event which occurred two months prior to our sampling, was the reason for the high numbers of Collembola on grasses at that time.

What is of interest here is ants and Collembola appear to be complementary groups in that they respond in opposite ways to flood and fire, and also possibly rain through vegetation, although the long term effects of these extreme events do not negatively affect faunas. We suggest that management of the arid zone should accept, and in fact facilitate, a mosaic of impacts on the fauna and flora at least at a local scale.

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Appendix 1 Nanya flood and fire trial sites, April 2012. Sweep data from plots 3 to 10 taken on April 13th. 100 single or 50 double paces.

Taxa		**Plots**																
		Flood		**Floog & Fire**		**Fire**		**Control**		**Flood**		**Floog & Fire**		**Fire**		**Control**		
Class	**Species**	**3 fenced**	**3 unfenced**	**4 fenced**	**4 unfenced**	**5 fenced**	**5 unfenced**	**6 fenced**	**6 unfenced**	**7 fenced**	**7 unfenced**	**8 fenced**	**8 unfenced**	**9 fenced**	**9 unfenced**	**10 fenced**	**10 unfenced**	**Total**
Collembola	*Corynephoria* sp. 1	47	34	26	30	1		3	4	10	37	1	41	3	7		1	**245**
	Corynephoria sp. 2	8	2	2	6									9	4		1	**32**
	Corynephoria sp. 3	1		1								1						**3**
	Corynephoria sp. 4			2														**2**
	Drepanura cinquilineata	2																**2**
	Acanthurella halei	1																**1**
Insecta	Pscoptera					2	1					2		2		5	1	**13**
	Orthoptera											1						**1**
	Thysanoptera	3	1	1	1							17		1		2		**26**
	Hemiptera Psylloidea										1	8	1	1				**11**
	Hemiptera Aphididae	5		1														**6**
	Hemiptera other	2	1	1	2			1	1	1	1	2				2		**14**
	Coleoptera adult	1		1		1		1		1			1	1		1	1	**9**
	Coleoptera larvae						1											**1**
	Mantodea		3															**3**
	Diptera													1				**1**
	Lepidoptera larvae		1	1	1													**3**
	Hymenoptera Formicidae	1			1					4	4	6	6	1	1			**24**
	Hymenoptera other	7	3	1		5		1		2	3			1	2	4		**29**
Arachnida	Araneae	5	1	1	4	1	3	3	8	2	2		1	2	2	6	3	**44**
	Acari Oribatoidea	2		5	1		5	2			1			1	2	4		**23**
	Acari Prostigmata	1	2										1					**4**
	Totals	**86**	**48**	**43**	**46**	**10**	**10**	**11**	**13**	**20**	**49**	**38**	**51**	**23**	**18**	**24**	**7**	**497**
	No. of taxa	**14**	**9**	**12**	**8**	**5**	**4**	**6**	**4**	**6**	**7**	**8**	**6**	**11**	**6**	**7**	**5**	

Appendix 2 Fauna collected from pitfalls on fire and flood monitoring plots at Ngeaela Station, April 2012.

Taxon	Species	3 fenced						3 unfenced						4 fenced					
		PF1	**PF2**	**PF3**	**PF4**	**PF5**	**Totals**	**PF1**	**PF2**	**PF3**	**PF4**	**PF5**	**Totals**	**PF1**	**PF2**	**PF3**	**PF4**	**PF5**	**Totals**
Collembola	cf *Katianna* sp.						**0**						**0**						**0**
	Corynephoria sp. 1	1	1				**2**			2		2	**4**			1		1	**2**
	Corynephoria sp. 2						**0**					3	**3**						**0**
	Corynephoria sp. 3						**0**						**0**						**0**
	Corynephoria sp. 4				2		**2**						**0**						**0**
	Imm *Corynephoria*					2	**2**						**0**						**0**
	Drepanura cinquilineata		4	3		3	**10**	1	3	4	5	3	**16**	2			11	4	**17**
	Acanthurella halei		1	3	1	1	**6**		3	1			**4**					2	**2**
	Immature Entomobryidae		1				**1**		1		1	3	**5**		6	1	1	1	**9**
Insecta	Thysanura						**0**						**0**						**0**
	Pscoptera						**0**						**0**						**0**
	Orthoptera						**0**						**0**			1			**1**
	Thysanoptera						**0**						**0**						**0**
	Neuroptera imm						**0**						**0**						**0**
	Hemiptera Psylloidea/Cicadellidae	1					**1**			1			**1**						**0**
	Hemiptera: Pseudacoccidae				3	1	**4**			29		1	**30**			1			**1**
	Hemiptera Aphididae						**0**				1		**1**						**0**
	Hemiptera other					1	**1**		1	1			**2**						**0**
	Isoptera						**0**						**0**						**0**
	Coleoptera adult				1		**1**						**0**					1	**1**
	Coleoptera larvae						**0**						**0**						**0**
	Mantodea						**0**						**0**						**0**
	Diptera	1		4		1	**6**		3	5	9	1	**18**	1		2		2	**5**
	Diptera larvae						**0**						**0**						**0**
	Lepidoptera	1					**1**						**0**						**0**
	Lepidoptera larvae						**0**			1			**1**						**0**
	Hymenoptera Formicidae	15	46	65	28	134	**288**	37	21	66	15	13	**152**	25	17	34	26	77	**179**
	Hymenoptera other	3		1			**4**					1	**1**			2			**2**
Arachnida	Araneae						**0**						**0**					2	**2**
	Acari Oribatoidea						**0**						**0**						**0**
	Acari Prostigmata						**0**		2	2	1	1	**6**		1	1			**2**
	Bdellidae					1	**1**						**0**						**0**
	Nanorchestidae						**0**						**0**						**0**
	Caeculidae						**0**						**0**						**0**
	Total	22	53	76	35	144	**330**	38	34	112	32	28	**244**	28	24	43	38	90	**223**

4 unfenced						5 fenced						5 unfenced						6 fenced						6 unfenced					
PF1	PF2	PF3	PF4	PF5	Totals	PF1	PF2	PF3	PF4	PF5	Totals	PF1	PF2	PF3	PF4	PF5	Totals	PF1	PF2	PF3	PF4	PF5	Totals	PF1	PF2	PF3	PF4	PF5	Totals
					0						**0**						**0**						**0**						**0**
	2	1	1		**4**	1			1		**2**						**0**			3			**3**			1			**1**
					0						**0**						**0**						**0**						**0**
					0						**0**						**0**						**0**						**0**
					0						**0**						**0**						**0**						**0**
					0						**0**						**0**						**0**						**0**
1	1	5	3	2	**12**					2	**2**						**0**						**0**						**0**
			1		**1**			1		2	**3**	1	2	1		3	**7**			1			**1**	1					**1**
		1			**1**						**0**			1		7	**8**		1				**1**			1			**1**
					0						**0**						**0**						**0**						**0**
					0						**0**						**0**						**0**						**0**
					0	1					**1**						**0**						**0**	1					**1**
					0						**0**						**0**						**0**						**0**
					0	1					**1**						**0**						**0**						**0**
					0						**0**						**0**						**0**						**0**
					0						**0**						**0**						**0**						**0**
					0						**0**						**0**						**0**						**0**
					0						**0**						**0**						**0**						**0**
				3	**3**						**0**						**0**						**0**						**0**
					0		1		9	1	**11**		1		1	5	**7**			1			**1**					2	**2**
					0						**0**						**0**						**0**						**0**
					0						**0**						**0**						**0**						**0**
1		6	2	1	**10**		2	1	1	2	**6**	4	2	3	2	6	**17**	4	1	1			**6**		3		2	2	**7**
					0						**0**						**0**						**0**						**0**
					0						**0**						**0**						**0**						**0**
					0						**0**				1		**1**						**0**						**0**
27	25	24	74	10	**160**	9	26	11	17	25	**88**	6	2	16	17	9	**50**	32	70	47	69	200	**418**	18	11	18	20	7	**74**
		1	1	2	**4**						**0**			1			**1**						**0**				1	1	**2**
					0						**0**			1			**1**				1	1	**2**		1	1	1		**3**
					0						**0**						**0**						**0**						**0**
					0			1	2	1	**4**	1					**1**						**0**				1		**1**
					0						**0**						**0**						**0**						**0**
					0				15	2	**17**	1					**1**						**0**						**0**
					0						**0**						**0**						**0**			1			**1**
29	28	38	82	18	**195**	12	29	14	45	35	**135**	13	7	23	21	30	**94**	36	72	53	70	201	**432**	20	15	22	25	12	**94**

Appendix 2 Collections from pitfall traps (Continued previos page).

Taxon	Species	7 fenced						7 unfenced						8 fenced					
		PF1	PF2	PF3	PF4	PF5	Totals	PF1	PF2	PF3	PF4	PF5	Totals	PF1	PF2	PF3	PF4	PF5	Totals
Collembola	cf *Katianna* sp.						**0**				1		**1**						**0**
	Corynephoria sp. 1						**0**		1			1	**2**						**0**
	Corynephoria sp. 2						**0**						**0**						**0**
	Corynephoria sp. 3						**0**						**0**						**0**
	Corynephoria sp. 4						**0**						**0**						**0**
	Imm *Corynephoria*						**0**						**0**						**0**
	Drepanura cinquilineata	2		1			**3**	22	6	10	5	4	**47**	1					**1**
	Acanthurella halei			1			**1**						**0**						**0**
	Immature Entomobryidae	1					**1**						**0**						**0**
Insecta	Thysanura						**0**						**0**						**0**
	Pscoptera						**0**						**0**						**0**
	Orthoptera						**0**						**0**						**0**
	Thysanoptera						**0**						**0**						**0**
	Neuroptera imm						**0**						**0**						**0**
	Hemiptera Psylloidea/Cicadellidae						**0**						**0**						**0**
	Hemiptera: Pseudacoccidae						**0**						**0**						**0**
	Hemiptera Aphididae						**0**						**0**						**0**
	Hemiptera other						**0**	1					**1**						**0**
	Isoptera						**0**						**0**						**0**
	Coleoptera adult		2		1		**3**						**0**				1		**1**
	Coleoptera larvae						**0**						**0**						**0**
	Mantodea						**0**						**0**						**0**
	Diptera	11	4	1	1		**17**	1	1			2	**4**	2			3	2	**7**
	Diptera larvae						**0**						**0**						**0**
	Lepidoptera						**0**						**0**						**0**
	Lepidoptera larvae						**0**						**0**						**0**
	Hymenoptera Formicidae	33	94	10000	50000	50000	**110127**	23	55	10	116	130	**334**	49	122	134	550	55	**910**
	Hymenoptera other						**0**			1	1	1	**3**					1	**1**
Arachnida	Araneae						**0**						**0**						**0**
	Acari Oribatoidea						**0**						**0**						**0**
	Acari Prostigmata						**0**					2	**2**						**0**
	Bdellidae						**0**			1			**1**						**0**
	Nanorchestidae						**0**						**0**						**0**
	Caeculidae						**0**						**0**						**0**
	Total	47	100	10003	50002	50000	**110152**	47	63	22	123	140	**395**	52	122	134	554	58	**920**

8 unfenced						9 fenced						9 unfenced						10 fenced						10 unfenced					
PF1	PF2	PF3	PF4	PF5	Totals	PF1	PF2	PF3	PF4	PF5	Totals	PF1	PF2	PF3	PF4	PF5	Totals	PF1	PF2	PF3	PF4	PF5	Totals	PF1	PF2	PF3	PF4	PF5	Totals
											0					1	**1**						**0**						**0**
2	4	5									**0**			1			**1**			1			**1**	1					**1**
											0	2					**2**						**0**					1	**1**
											0						**0**						**0**						**0**
											0						**0**						**0**						**0**
											0						**0**						**0**						**0**
6	7	5	7	1							**0**						**0**						**0**		1	1			**2**
								2	1	7	**10**		4	4	8		**16**					1	**1**						**0**
	4	1				3	3			1	**7**	1	3	1	3		**8**		1	3	6		**10**		1			2	**3**
											0						**0**	1					**1**						**0**
1											**0**						**0**						**0**						**0**
			1								**0**				1		**1**						**0**						**0**
											0						**0**						**0**						**0**
											0						**0**						**0**						**0**
											0		1				**1**						**0**						**0**
											0						**0**						**0**	1					**1**
											0						**0**						**0**						**0**
			1								**0**						**0**						**0**						**0**
											0						**0**						**0**						**0**
		1									**0**	1		1	1		**3**				1		**1**						**0**
											0						**0**						**0**						**0**
											0						**0**						**0**						**0**
	2		1	2			1	2	2	6	**11**	5	6	1	4		**16**		1	2	1	4	**8**	1		1		1	**3**
											0		1				**1**						**0**						**0**
											0						**0**						**0**						**0**
											0						**0**						**0**						**0**
44	200	300	70	84		3	2	8	8	25	**46**	25	44	29	58	5000	**5156**	37	21	13	7	9	**87**	43	44	22	69	45	**223**
						1		1			**2**				1		**1**						**0**						**0**
							1				**1**		1	1		1	**3**					1	**1**				1		**1**
											0		1				**1**						**0**				1		**1**
1											**0**		2	3	4	1	**10**			2		3	**5**						**0**
									1		**1**						**0**						**0**						**0**
										10	**10**		6		5		**11**			5	2	1	**8**	6	1	3		1	**11**
											0						**0**						**0**						**0**
54	217	312	80	87		7	7	13	12	49	**88**	34	69	41	85	5003	**5232**	38	23	26	17	19	**123**	52	47	27	71	50	**247**