Agriculture, Ecosystems and Environment 163 (2012) 54–60

Contents lists available at SciVerse ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Using insect diversity for determining land restoration development: Examining the influence of grazing history on ant assemblages in rehabilitated pasture

Elizabeth R. Williams[a,*], David R. Mulligan[a], Peter D. Erskine[a], Kristine P. Plowman[b]

[a] Centre for Mined Land Rehabilitation, The University of Queensland, Brisbane, Queensland 4072, Australia
[b] Biodiversity Assessment and Management, P.O. Box 1376, Cleveland, Queensland 4163, Australia

ARTICLE INFO

Article history:
Received 20 July 2011
Received in revised form 23 January 2012
Accepted 27 February 2012
Available online 27 March 2012

Keywords:
Ants
Rehabilitation
Pasture
Post-mined landscapes
Buffel grass

ABSTRACT

Ant assemblages, used widely as bioindicators of land management practices, were sampled in rehabilitated pastures and surrounding habitats at Norwich Park Coal Mine in central Queensland, Australia. As the end-use goal of a number of rehabilitated mine sites in the region is sustainable pasture-land, the aim of this study was to investigate the influence of varying grazing histories on ant fauna, to provide further understanding on the function of rehabilitated agroecosystems and multi-trophic interactions. Examination of seven study sites revealed three distinct ant assemblages, broadly reflecting mining and grazing history. Rehabilitated pastures where grazing had ceased 2 years prior to ant sampling contained low species richness with a basic ant composition, regardless of stocking rate, and was similar to ungrazed rehabilitated pasture. The rehabilitated pasture with continual low intensity grazing showed ant compositional similarities to the neighboring unmined pasture, although assemblage descriptors were intermediate between unmined and rehabilitated sites. Buffel grass (*Pennisetum ciliare*, basionym *Cenchrus ciliaris*) and other stoloniferous or rhizomatous grasses were the principal influence on ant assemblages, with grazing reducing the ground dominance of such grasses and providing a more favorable habitat for a wider range of ant species.

1. Introduction

While the restoration of post-industrial landscapes may justifiably aim for the reinstatement of 'natural' ecosystems, the development of agro-ecological outcomes has become a suitable endpoint for land rehabilitation. In the central Queensland coalfields (Australia), a commonly desired rehabilitative end-goal is the return of post-mined lands to grazing pastures due to the predominance of cattle and agricultural production in the region. Following mining, land revegetation typically involves the seeding of introduced grasses and native trees and shrubs to provide shade for livestock (Roe et al., 1996). Rehabilitated pastures in the region are predominantly composed of introduced buffel (*Pennisetum ciliare*, basionym *Cenchrus ciliaris*; Simon, 2010) and Rhodes (*Chloris gayana*) grasses, which are selected for their rapid growth and proliferation that lead, in part, to stabilizing the soil matrix (Harwood, 1997).

However, it has been suggested that the implementation of cattle grazing, at typical stocking rates of the area, could be unsustainable on rehabilitated pastures given (1) the increased potential for erosion on steep slopes of waste material, (2) the highly saline and sodic mine overburden with highly modified soil-nutrient concentrations, and (3) the stripping and handling procedures can confound the quality of topsoil used on the overburden (Grigg, 1999, 2001; Grigg et al., 2000). Still, cattle grazing may be ecologically beneficial among recovering areas by reducing the dominance of buffel grass, which can otherwise lead to the deterioration of native ecological systems through decreasing local plant and animal biodiversity, escaping into non-target areas and increasing the risk of fire frequency and intensity (Friedel et al., 2006; Smyth et al., 2009).

Recently, research studies in central Queensland have attempted to determine the sustainability of rehabilitated pastures exposed to different grazing intensities, with an emphasis on the relationship between cattle stocking rates, the distribution of vegetation and local soil characteristics. These findings would suggest that stocking rates similar to unmined pastures may be achieved on some areas of rehabilitation, although areas with slopes greater than 10% and or high salinity are more susceptible to degradation (Bisrat et al., 2004; Grigg et al., 2006). So far, these assessments have targeted vegetation and soil biophysical properties; however, questions regarding faunal bioindicators, which may contribute to a deeper understanding of the long-term component of sustainability for these rehabilitated pastures, remain to be examined in more detail. In this regard, the examination of ant

* Corresponding author. Tel.: +61 7 334 64187; fax: +61 7 334 64056.
E-mail addresses: e.williams@cmlr.uq.edu.au, drelizabethrwilliams@gmail.com (E.R. Williams).

0167-8809/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
doi:10.1016/j.agee.2012.02.017

assemblages (often used as bioindicators of ecosystem function (Hoffmann and Andersen, 2003; Lobry de Bruyn, 1999)), could be examined to assess rehabilitation success and land management practices, such as at Norwich Park Coal Mine in central Queensland. For these reasons, the purpose of the present study was to investigate the suitability of ant assemblages as bioindicators of post-mined land rehabilitation by comparing their abundance and distribution among sites having different cattle grazing histories. With this study design, it was our intention to more effectively describe the function of rehabilitated agroecosystems multi-trophic interactions using a faunal indicator in terms of rehabilitative success.

2. Methods

2.1. Description of field sites

Norwich Park Coal Mine is located approximately 90 km north-east of Emerald in central Queensland, Australia (22°47′58″S, 148°29′48″E; Fig. 1). The climate is considered to be semi-arid with an average annual rainfall of 660 mm, the majority of which falls between December and March (Bureau of Meteorology, 2010). The region is primarily used as pasture-land and is composed of a mixture of pasture species (both introduced and native) and *Eucalyptus populnea*/*Acacia harpophylla* woodland. Seven proximally distributed study sites were examined (Fig. 2) and their respective management histories described (Table 1). Five of these study sites (three of which were based on pre-established paddocks; Bisrat et al., 2004) were located on rehabilitated pastures, incorporating sites with no (RP0), very low (RPV), low (RPL), medium (RPM) and high grazing intensities (RPH). Each site had similar rehabilitative histories including the recontouring of spoil to create landform, spreading of stored topsoil and revegetating with grass species. Grazing was established in February 2000 and cattle were removed from the paddocks with low (RPL), medium (RPM) and high (RPH) stocking rates in November 2007; however, grazing had continued at the very low stocked pasture (RPV) until the time of ant sampling. Two unmined sites were also examined, including (1) an unmined pasture-land (UPH) cleared regularly for pastoral use and grazed at typical stocking rates of the region (3 ha head^{-1}) until cattle were removed approximately 2 years prior to ant sampling, and (2) an unmined remnant eucalypt woodland (UWV), located within the paddock that included the rehabilitated pasture with very low grazing.

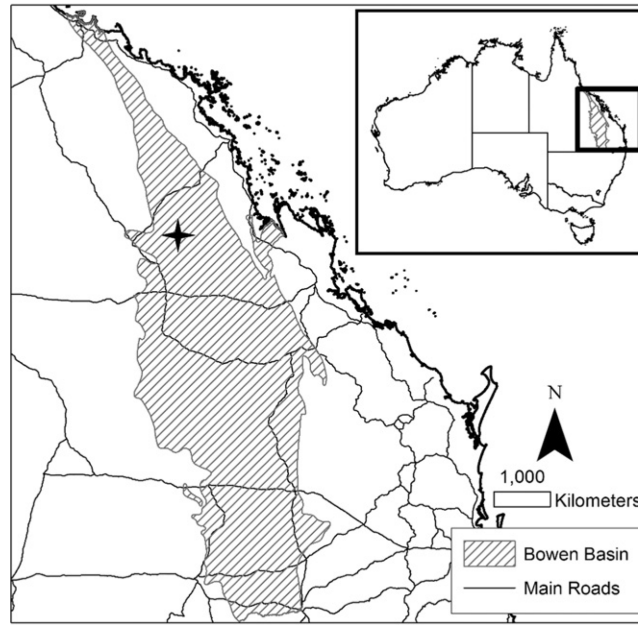

Fig. 1. Location of Norwich Park Mine (black star) in Queensland, Australia.

2.2. Ant sampling and habitat characterization

Field surveys were conducted between 6 and 15 October 2009, during clear weather with mean minimum–maximum temperatures of 14–32 °C and 2 mm rain (Bureau of Meteorology, 2010). At each site, three grids were randomly positioned and ants sampled by pitfall traps and hand collections. Twenty-five pitfall traps were positioned in each grid with five rows of five traps and 2.5 m between traps. Pitfalls consisted of 50 mL centrifuge tubes (30 mm diameter) filled with approximately 25 mL non-glycol

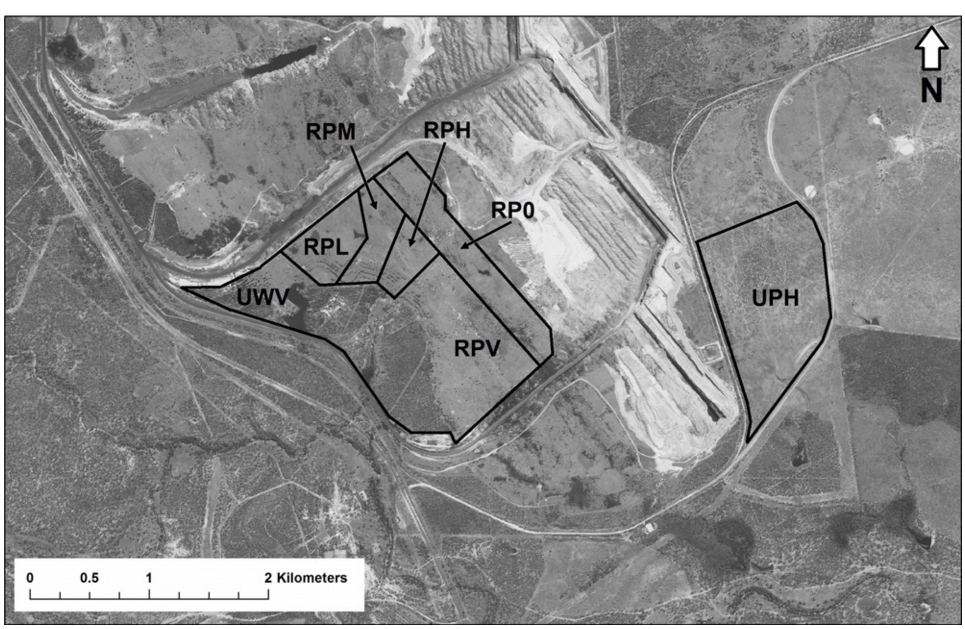

Fig. 2. Aerial photograph of site boundaries within study location.

Table 1
Site details and disturbance history at Norwich Park Mine.

	Site	Code	Paddock size (ha)	Year of pasture seeding	Grazing	Stocking rate (ha head^{-1})
Unmined	Woodland with very low grazing	UWV	180[a]	NA	Continuous from February 2000	14
	Pasture with high grazing	UPH	150	NA	Continuous until November 2007	3
Rehabilitation (continuously grazed)	Pasture with very low grazing	RPV	180[a]	1993	Continuous from February 2000	14
Rehabilitation (grazing ceased)	Pasture with no grazing	RP0	62	1992	NA	NA
	Pasture with low grazing	RPL	31	1992	February 2000–November 2007	7.5/5.2
	Pasture with medium grazing	RPM	23	1992	February 2000–November 2007	4.6/3.8
	Pasture with high grazing	RPH	17	1993	February 2000–November 2007	3.4/2.4

Site codes will be used throughout the remainder of the paper. Stocking rates were increased at three paddocks in August 2002 and values given in the respective column signify rates prior and post stocking intensification.
[a] 180 ha paddock that contained both rehabilitated pasture and unmined woodland remnants.

Table 2
Site values for ant assemblage descriptors.

	Site code	Species richness	Relative abundance	Diversity	Dominance
Unmined	UWV	58	775	0.94	0.17
	UPH	34	532	0.88	0.26
Rehabilitated pasture (continuously grazed)	RPV	28	386	0.86	0.28
Rehabilitated pasture (grazing ceased)	RP0	18	338	0.86	0.22
	RPL	23	292	0.81	0.29
	RPM	19	572	0.79	0.38
	RPH	22	387	0.84	0.28

Ant assemblage descriptors are defined as species richness (number of species), relative abundance (number of individuals collected; scaled at trap level), Simpson's reciprocal diversity (where 0 = no diversity and 1 = highly diverse) and the Berger-Parker dominance index (0 = one species highly dominant, 1 = no single species dominant). Mean replicate values (n = 3) are presented with the exception of total site species richness. Site codes are detailed in Table 1.

based coolant to act as a killing/preserving agent and to minimize evaporation. This solution was used as an alternative to ethylene glycol or alcohol blend, to minimize the harm to non-target vertebrates (Bestelmeyer et al., 2000). To reduce 'digging-in effects', where soil disturbance attracts certain species of ants (Greenslade, 1973), a soil corer was used to produce suitably sized holes for traps and resulted in minimal disturbance to the surrounding soil. Traps were immediately opened on insertion into the ground and operated for 6 days. Hand collections were conducted for 30 min at each grid between 8–11 a.m. and 2–5 p.m. (avoiding daily temperature extremes) and involved searching for ants in and under leaf litter, woody debris, rocks and soil, as well as on vegetation.

Ants were identified to genera following Shattuck (1999) and to morphospecies (hereafter termed 'species') according to numerous resources (Andersen, 2000; Heterick and Shattuck, 2011; McArthur, 2007; Shattuck and Barnett, 2010). Notably, alates (winged reproductive castes) were excluded as their origin is unknown, and worker ants unable to be identified to species level were given an identification code unique to this study. A subsample of species was further verified for confirmation of identification (Chris Burwell, Queensland Museum) and voucher specimens entered into the museum collection.

Environmental variables (particularly those influencing ant species composition) were recorded at each grid including ground cover, litter depth and incorporation, foliage projective cover (FPC), as well as vegetation species presence, abundance, height, spread and proportion of standing dry material. Additional descriptions of replicate and site characteristics were noted including aspect, vegetation health, soil descriptors and dominant species in each vegetation stratification (canopy, subcanopy, midstorey and understorey).

2.3. Statistical analysis

Prior to grazing, it was assumed that the ant assemblages in each paddock were comparable due to similar rehabilitation techniques, site attributes, vegetation characteristics and paddock proximity. However, insufficient historical data on the ant fauna was available to determine the status of those particular sites prior to grazing disturbance.

Basic assemblage descriptors were determined including species richness, Simpson's reciprocal diversity and the Berger-Parker dominance index. The abundance of ant species metric was scaled at trap level to reduce distortions that can occur when traps are placed near nest entrances or foraging trails (Hoffmann and Andersen, 2003). This was performed using a 6-point scale, where 1 = 1 specimen, 2 = 2–5, 3 = 6–10, 4 = 11–20, 5 = 21–50 and 6 = >50 (as per Andersen and Spain, 1996). PRIMER v6 (Clarke and Gorley, 2006) was used to compute multivariate analyses. This included cluster analysis (using Bray–Curtis similarity and presence/absence data) to compare the similarity of ant assemblages between sites and Principal Component Analysis (PCA) ordination (using Euclidean distance resemblance matrices) to investigate differences in vegetation and habitat data between sites. The BIOENV function, using Spearman Rank correlations, was used to examine the relationship between environmental data and the ant assemblages. Regression analyses were also used where appropriate.

3. Results

A total of 29,545 ants were collected by pitfall traps and hand sampling, comprising 88 species from 30 genera. *Camponotus* was the most speciose genus with 10 species, followed by *Iridomyrmex* (9). The latter genus was the most abundant with 23,573

Table 3
Ant species collected exclusively or predominantly at unmined or rehabilitated pasture sites.

Unmined site/s	Rehabilitated pasture/s
Exclusively	
Cardiocondyla nuda	*Dolichoderus* sp. NP1
Froggattella kirbii	
Meranoplus species	
Monomorium bicorne	
Monomorium rothsteini	
Rhytidoponera species (large)	
Solenopsis (*Diplorhoptrum*) sp. NP1	
Predominantly	
Crematogaster species[a]	*Pheidole* species
Melophorus species	*Rhytidoponera* sp. NP2 (*metallica* group)
Opisthopsis rufithorax	
Polyrhachis species	
Stigmacros species[a]	

[a] Species collected in unmined sites and RPV only.

specimens; however, 17,157 *Iridomyrmex sp. NP4* were collected at the unmined native pasture site (UPH) with the majority of these being collected in just five pitfall traps. This is assumed to be due to traps being placed near foraging trails or nests and supports the use of relative abundance in analyses. The unmined woodland site (UWV) had the highest species richness, relative abundance and diversity, as well as the lowest dominance by a single species (Table 2). At the rehabilitated sites where grazing ceased 2 years previously (RPL, RPM and RPH) and at the ungrazed rehabilitated pasture (RP0), species richness values were lower than other sites. Ant species lists of sites were inspected for patterns of species distribution (key species outlined in Table 3), with ant biology also examined to determine trends in habitat use and function.

Cluster ordination calculated that ant assemblages of the unmined sites were less than 25% similar to the rehabilitated pastures (Fig. 3); however, composition between the unmined sites was still markedly incongruent. Within the rehabilitated pastures, the continually grazed site (RPV) was the most dissimilar.

Computation of BIOENV for environmental data determined seven habitat features that explained site variation to 99.1%. When these variables were used in PCA analysis (Fig. 4), buffel grass

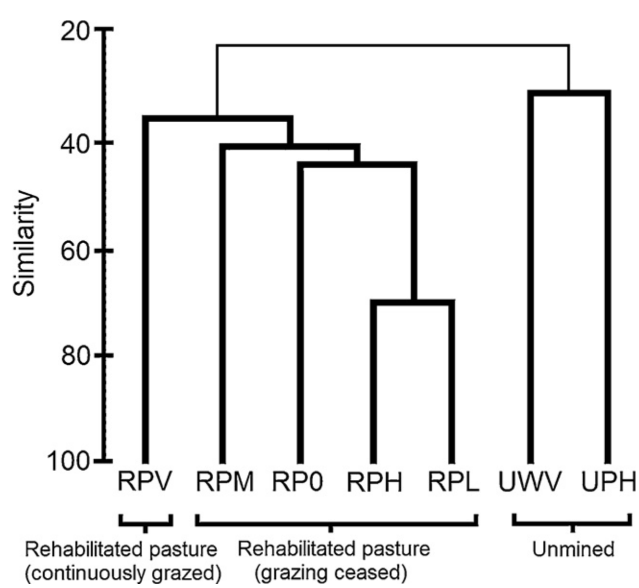

Fig. 3. Similarity of ant assemblage composition between sites using cluster analysis. Sites linked by thick lines are statistically similar (SIMPROF, $p < 0.05$). Presence/absence data is used and a Bray–Curtis resemblance matrix computed. Site codes are detailed in Table 1.

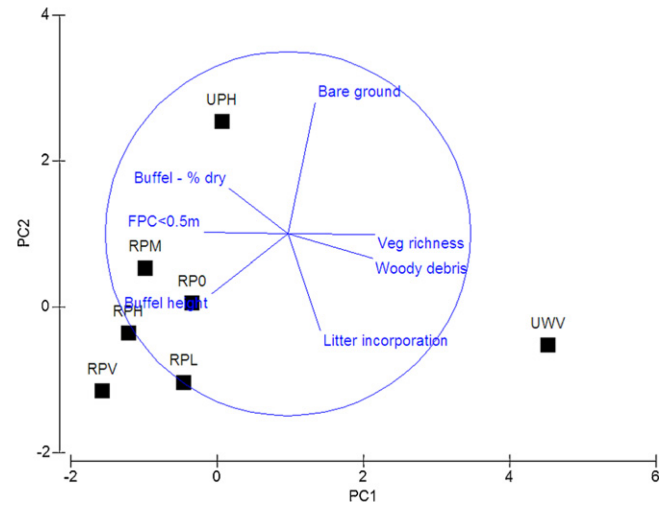

Fig. 4. Grouping of sites by Principal Component Analysis of environmental variables. Euclidean distance resemblances were used on mean replicate data. Site codes are detailed in Table 1.

height was the main contributor for grouping rehabilitated pastures together. Bare ground at the native pasture site, and woody debris, litter and vegetation species richness at the woodland site segregated these two unmined sites from the rehabilitated pastures. In terms of the relationship between environmental variables and ant assemblage composition, BIOENV computed that 91.9% of ant fauna variation was explained by buffel grass cover (measured as a proportion of the total vegetation cover).

Ground cover was dominated by standing dry vegetation at a majority of the pasture sites (Fig. 5), particularly at the continuously grazed rehabilitated pasture (RPV), with live vegetation secondarily dominant. Leaf litter and woody debris cover were high at the woodland site, and bare ground was highest at unmined sites. In terms of vegetation species, buffel grass was the main cover at all rehabilitated pasture sites (Fig. 6); in particular, at sites where grazing ceased 2 years previously, buffel grass contributed to more than 90% of all vegetation cover. Buffel grass cover was reduced at the continually grazed pasture (RPV) and was only a minor vegetation component in the unmined sites. There was a significant negative correlation between vegetation cover by stoloniferous and rhizomatous grasses and ant species richness ($r^2 = 0.7818$, $F(1, 19) = 68.09$, $p < 0.01$; Fig. 7).

4. Discussion

This study investigated the suitability of ant assemblages as bioindicators of post-mined land rehabilitation, and was anticipated to lead to further understanding of rehabilitated agroecosystems and multi-trophic interactions, by comparing their abundance and distribution among sites with varying cattle grazing histories.

The ant assemblages at the seven study sites examined at Norwich Park Coal Mine were clustered into three distinct groups, broadly reflecting the grazing and mining histories. There was little difference between the ant assemblages on rehabilitated pasture despite different grazing histories. Additionally, the ant fauna at the three rehabilitated pastures where grazing ceased 2 years prior to sampling resembled the ungrazed pasture. In particular, species richness values were comparable between sites, and ant assemblages were at least 50% similar in composition. One scenario for the minimal disparity between these sites is that ants may be inadequate bioindicators in pasture landscapes. Specifically, there is disagreement in the published literature of

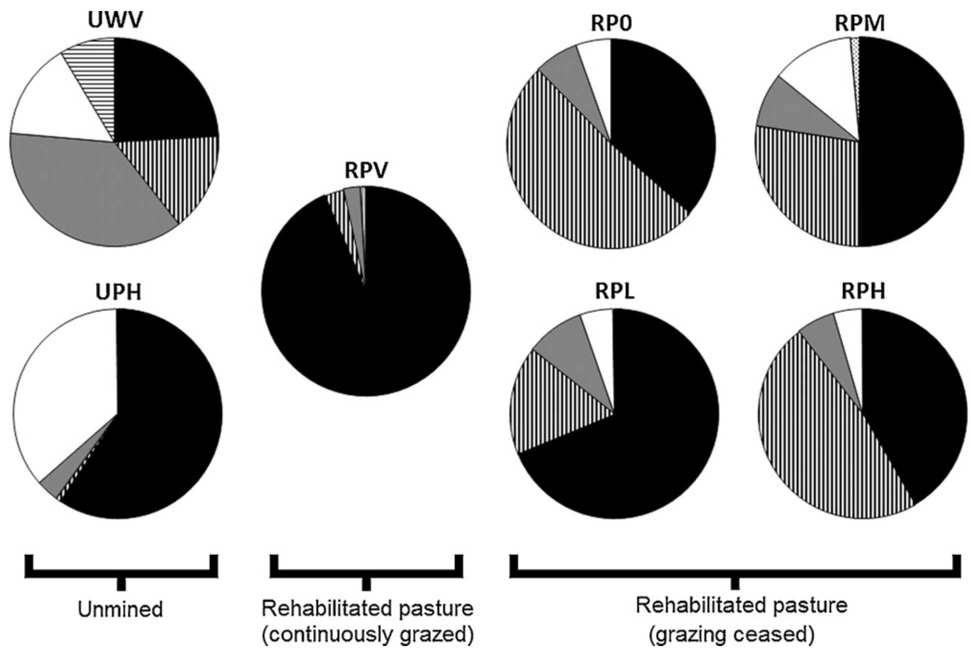

Fig. 5. Mean proportion of ground cover at each site, incorporating standing dry vegetation (black), live vegetation (vertical lines), leaf litter (grey), bare ground (white), woody debris (horizontal lines) and rocks (dotted fill). Site codes are detailed in Table 1.

the suitability of ants as bioindicators in simplified habitats such as grasslands. Several studies have found that ants show a minimal response to grazing (Hadden and Westbrooke, 1999; Hoffmann, 2000; Read and Andersen, 2000), while other research has found distinct differences between the ant fauna on grazed and ungrazed grasslands (Hutchinson and King, 1980; Woinarski et al., 2002). It has been proposed that ant response to disturbance is dependent on the extent of habitat alteration (Barrow et al., 2007; Hoffmann et al., 2000; Hoffmann, 2003; Read and Andersen, 2000; Schneider, 2004). In particular, disturbances that have minimal impact on habitat structure often cause limited response in ant assemblages (Bestelmeyer and Wiens, 1996; Farji-Brener et al., 2002; York, 2000). Disturbance in grasslands may result in a more open habitat, which has relatively little impact on the original fauna. That is, the changes in structurally simple vegetation at ant-level are not distinct enough to trigger a response.

Another interpretation is that the extended period (2 years) since the rehabilitated pastures were grazed has given ant assemblages and vegetation ample time to restructure. Rehabilitation monitoring records from 2007 suggest that vegetation in the

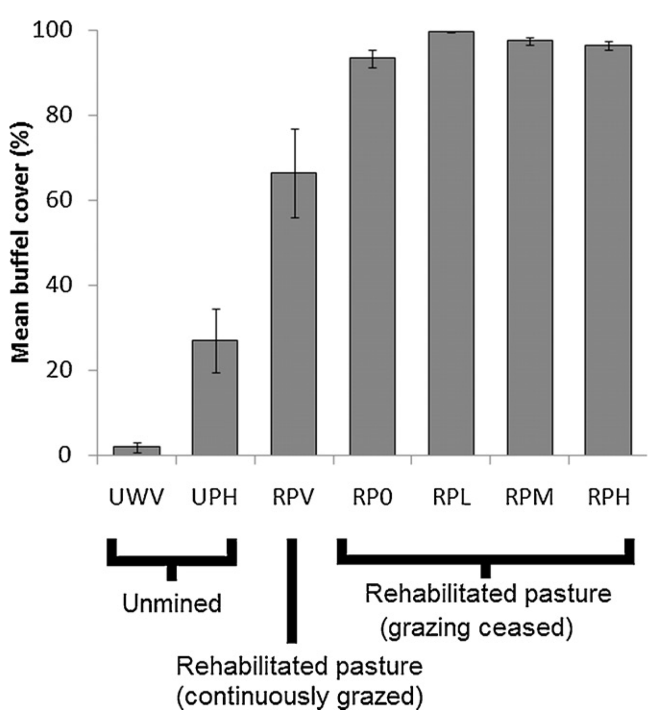

Fig. 6. Mean vegetation cover consisting of buffel grass at each site. Standard error is depicted by error bars. Site codes are detailed in Table 1.

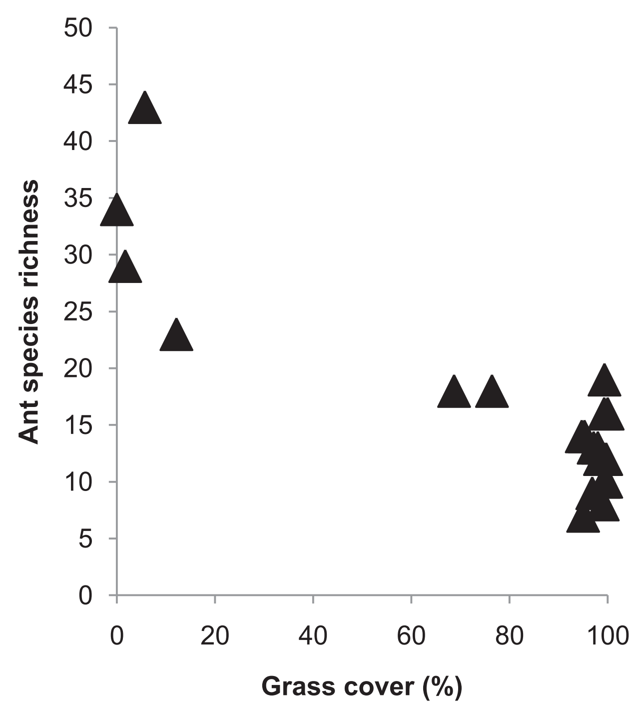

Fig. 7. Correlation between cover of stoloniferous/rhizomatous grasses and ant species richness at each replicate.

paddocks during grazing was markedly dissimilar to the habitat data collected during ant sampling in the current study in 2009. In particular, slumpage cracks, erosion gullies and large bare patches were recorded in 2007 and sites were described as being heavily grazed and trampled (Emmerton and Elsol, 2007). Furthermore, grass height was recorded at less than 40 cm (Emmerton and Elsol, 2007), which is substantially shorter than during ant sampling where mean grass height was 1.2 m in the same paddocks. Additionally, higher than average rainfall during growing seasons in the 2 years since grazing ceased (Bureau of Meteorology, 2010) may have contributed to rapid plant growth. Therefore, considering ant response is dependent on the degree of modifications in habitat complexity, it is likely that ant fauna in the grazed paddocks in 2007 would have been different to the ant assemblages described in this study.

Further support for time since grazing as the cause of site similarity is gathered when examining the continuously grazed rehabilitated pasture. Cattle had grazed this paddock at very low stocking rates for almost 8 years at the time of ant sampling. Although ant assemblage composition resembled the ant fauna in rehabilitated pasture where grazing had ceased 2 years prior, distinctions were apparent. Specifically, species richness was higher, and several species were present that were not collected at the other rehabilitated pastures but were common at unmined sites. Similar patterns were recorded for environmental variables. All rehabilitated pasture sites were similar in multivariate analysis, dominant ground covers and vegetation richness values; however, the continuously grazed pasture had reduced live vegetation cover and buffel grass cover was at levels between that found in the unmined sites and other rehabilitated pastures.

Ant fauna and vegetation at rehabilitated pastures were dissimilar to the unmined sites. For instance, granivorous species (such as *Monomorium bicorne*, *Monomorium rothsteini* and *Meranoplus* sp. NP1 (*diversus* group)) were only collected in unmined sites. The unmined pasture contained considerably higher species richness compared to the rehabilitated pastures, and its assemblage composition was more similar to the woodland. The increased collection of litter-dwelling and arboreal ants at the woodland site, including *Solenopsis* (*Diplorhoptrum*) sp. NP1, *Froggattella kirbii* and species of *Crematogaster* and *Stigmacros*, is characteristic of habitats with greater structural complexity.

It is suggested that the primary influence on ant fauna at Norwich Park Mine is the growth habit of grasses, particularly those that develop into dense swards, such as grasses with stoloniferous and rhizomatous habits. This incorporates species such as sabi (*Urochloa mosambicensis*), buffel and Rhodes grasses. Ant species richness was significantly negatively correlated to grass cover by these species, and ant assemblage composition appeared predominantly determined by buffel grass cover alone. This is in line with previous research that suggests buffel grass strongly influences ant fauna (Binks et al., 2005; Schneider, 2004), as well as vegetation and other taxa (Butler and Fairfax, 2003; Fairfax and Fensham, 2000; Flanders et al., 2006; Friedel et al., 2006).

The influence of buffel grass (and other sward-forming grasses) on ant assemblages may be due to differences in microclimate conditions at ground level. In particular, insolation is reduced (Schneider, 2004), which is important in ant establishment and activity (Andersen, 1986a,b, 1991; Dauber et al., 2005; Debuse et al., 2007). At Norwich Park Mine, many thermophilic ants, such as *Opisthopsis*, *Melophorus* and *Meranoplus* species, were reduced or absent at the rehabilitated pasture sites where buffel grass cover exceeded 90% and ground insolation was consequently reduced. Habitat complexity at ground level may also be influencing the ant species present, as many large species (such as *Rhytidoponera tenuis* and numerous ground-nesting *Polyrhachis* species) were more speciose and abundant in the unmined sites. Smaller ants, however, including several *Pheidole* species and *Rhytidoponera* sp. NP2 (*metallica* group), were increased in species and/or number at the rehabilitated pasture sites. It is possible that the increased grass cover and reduced bare ground at the rehabilitated pasture sites impeded the mobility and foraging capacity of large ants. This is similar to the 'size-grain hypothesis', which suggests that as body size decreases, environmental rugosity (or complexity) increases (Kaspari and Weiser, 1999) and has been successfully applied in ant assemblages (Espadaler and Gomez, 2001; Farji-Brener et al., 2004). The hypothesis proposes that in highly rugose habitats, long legs and large size may impede the ability of ants to penetrate small interstices; however, in less rugose habitats long legs and large size are more energy efficient in mobility, as well as advantageous in resistance to desiccation (Kaspari, 1993; Kaspari and Weiser, 1999).

5. Conclusion

This study aimed to determine whether different stocking rates of cattle influenced ant fauna on post-mined rehabilitated pastures. The examination of ants in such an environment has not been previously published, and the use of faunal bioindicators (with the exception of cattle live-weight gains) is similarly absent in the literature. There were three distinct ant assemblages, which reflected the mining and grazing histories of the study sites. Minimal disparity was found between rehabilitated pasture with no, low, medium and high levels of cattle grazing. However, livestock had been removed from grazed paddocks approximately 2 years prior to ant sampling, allowing vegetation and ant assemblages to restructure. Ant fauna on a rehabilitated pasture with continuously very low grazing was similar to other rehabilitated pastures, although resemblances to unmined reference sites were apparent. Ant assemblage variation in this study was explained by the cover of sward-forming grasses (particularly buffel grass), which are typically included in revegetation procedures or left uncontrolled on incursion. Such cover decreased bare ground and insolation (affecting thermophilic species) and increased vegetation complexity at ground level (possibly influencing the mobility of large species). Ant biodiversity is unlikely to improve on rehabilitated pastures at Norwich Park Mine unless buffel grass cover declines. Considering the bioindicator capability of ants and their role in ecosystem function, such claims raise concern for the successful rehabilitation of the pastures examined. Other benefits from a reduction in buffel grass cover include improving floristic biodiversity and decreasing the flammability risk of large amounts of standing dry vegetation.

Acknowledgments

The authors wish to thank Bernie Kirsch and BHP Billiton Mitsubishi Alliance for site access, as well as Darcy Murray and Luke Schuler for ground support. Field assistance was provided by Anne Schneider, with ant taxonomic verification by Chris Burwell. This research was funded by the Queensland Resources Council, Coal Minesite Rehabilitation Trust Fund.

References

Andersen, A.N., 1986a. Diversity, seasonality and community organization of ants at adjacent heath and woodland sites in south-eastern Australia. Australian Journal of Zoology 34, 53–64.
Andersen, A.N., 1986b. Patterns of ant community organization in mesic southeastern Australia. Australian Journal of Ecology 11, 87–97.
Andersen, A.N., 1991. Responses of ground foraging ant communities to three experimental fire regimes in a savanna forest of tropical Australia. Biotropica 23, 575–585.
Andersen, A.N., 2000. The Ants of Northern Australia: A Guide to the Monsoonal Fauna. CSIRO Publishing, Collingwood, Victoria.
Andersen, A.N., Spain, A.V., 1996. The ant fauna of the Bowen Basin, in the semi-arid tropics of central Queensland (Hymenoptera: Formicidae). Australian Journal of Entomology 35, 213–221.

Barrow, L., Parr, C.L., Kohen, J.L., 2007. Habitat type influences fire resilience of ant assemblages in the semi-arid tropics of Northern Australia. Journal of Arid Environments 69, 80–95.

Bestelmeyer, B.T., Wiens, J.A., 1996. The effects of land use on the structure of ground-foraging ant communities in the Argentine Chaco. Ecological Applications 6, 1225–1240.

Bestelmeyer, B.T., Agosti, D., Alonso, L.E., Brandão, C.R.F., Brown, W.L., Delabie, J.H.C., Silvestre, R., 2000. Field techniques for the study of ground-dwelling ants: an overview, description, and evaluation. In: Agosti, D., Majer, J.D., Alonso, L.E., Schultz, T.R. (Eds.), Ants: Standard Methods for Measuring and Monitoring Biodiversity. Smithsonian Institute, Washington, pp. 122–144.

Binks, R., Cann, A., Perks, S., Silla, A., Young, M., 2005. The effect of introduced buffel grass (*Cenchrus ciliarus* L.) on terrestrial invertebrate communities in the Pilbara region, Western Australia. BSc Honours Thesis, University of Western Australia.

Bisrat, S.A., Mullen, B.F., Grigg, A.H., Shelton, H.M., 2004. Net primary productivity and rainfall use efficiency of pastures on reconstructed land following open-cut coal mining in central Queensland, Australia. Tropical Grasslands 38, 47–55.

Bureau of Meteorology, 2010. Weather Station Data. Australian Government. Available at: http://www.bom.gov.au/climate/data/weather-data.shtml (accessed 14.05.10).

Butler, D.W., Fairfax, R.J., 2003. Buffel grass and fire in a Gidgee and Brigalow woodland: a case study from central Queensland. Ecological Management and Restoration 4, 120–125.

Clarke, K.R., Gorley, R.N., 2006. PRIMER v6: User Manual/Tutorial. PRIMER-E, Plymouth.

Dauber, J., Purtauf, T., Allspach, A., Voigtlander, K., Wolters, V., 2005. Local vs. landscape controls on diversity: a test using surface-dwelling soil macroinvertebrates of different mobility. Global Ecology & Biogeography 14, 213–221.

Debuse, V.J., King, J., House, A.P.N., 2007. Effect of fragmentation, habitat loss and within-patch habitat characteristics on ant assemblages in semi-arid woodlands of eastern Australia. Landscape Ecology 22, 731–745.

Emmerton, B.R., Elsol, J., 2007. Norwich Park Mine, Rehabilitation Monitoring (eighth monitoring, 30th April to the 11th May 2007). Report Prepared for BHP Billiton Mitsubishi Alliance by B.R. Emmerton Pty Ltd. Environmental Consulting and Management.

Espadaler, X., Gomez, C., 2001. Formicine ants comply with the size-grain hypothesis. Functional Ecology 15, 136–139.

Fairfax, R.J., Fensham, R.J., 2000. The effect of exotic pasture development on floristic diversity in central Queensland, Australia. Biological Conservation 94, 11–21.

Farji-Brener, A.G., Corley, J.C., Bettinelli, J., 2002. The effects of fire on ant communities in north-western Patagonia: the importance of habitat structure and regional context. Diversity and Distributions 8 430, 235–243.

Farji-Brener, A.G., Barrantes, G., Ruggiero, A., 2004. Environmental rugosity, body size and access to food: a test of the size-grain hypothesis in tropical litter ants. Oikos 104 433, 165–171.

Flanders, A.A., Kuvlesky Jr., W.P., Ruthven III, D.C., Zaiglin, R.E., Bingham, R.L., Fulbright, T.E., Hernandez, F., Brennan, L.A., 2006. Effects of invasive Asian exotic grasses on south Texas rangeland breeding birds. The Auk 123, 171–182.

Friedel, M., Puckey, H., O'Malley, C., Waycott, M., Smyth, A., Miller, G., 2006. Buffel Grass, Both Friend and Foe: An Evaluation of the Advantages and Disadvantages of Buffel Grass Use, and Recommendations for Future Research. Desert Knowledge Cooperative Research Centre, Alice Springs.

Greenslade, P.J.M., 1973. Sampling ants with pitfall traps: digging-in effects. Insectes Sociaux 20, 343–353.

Grigg, A., 1999. A Preliminary Land Suitability Evaluation for Cattle Grazing as a Post-mining Land Use on Rehabilitated Areas at Goonyella Riverside Mine. Centre for Mined Land Rehabilitation, The University of Queensland, Brisbane.

Grigg, A.H., 2001. How much grazing? Options for rehabilitation grasslands after open-cut coal mining in central Queensland. Ecological Management and Restoration 2, 151–152.

Grigg, A., Shelton, M., Mullen, B., 2000. The nature and management of rehabilitated pastures on open-cut coal mines in central Queensland. Tropical Grasslands 34, 242–250.

Grigg, A., Mullen, B., Byrne, T., Shelton, M., 2006. Sustainable Grazing on Rehabilitated Lands in the Bowen Basin. Centre for Mined Land Rehabilitation, The University of Queensland, Brisbane.

Hadden, S.A., Westbrooke, M.E., 1999. A comparison of the Coleoptera, Araneae and Formicidae fauna in a grazed native grassland remnant of Victoria. In: Ponder, W., Lunney, D. (Eds.), The Other 99%: The Conservation and Biodiversity of Invertebrates. The Royal Zoological Society of New South Wales, Mosman.

Harwood, M.R., 1997. The Selection of New Pasture Grasses for the Revegetation of Open-cut Coal Mines in Central Queensland. Doctor of Philosophy Thesis, The University of Queensland.

Heterick, B.E., Shattuck, S.O., 2011. Revision of the ant genus *Iridomyrmex* (Hymenoptera. Formicidae). Zootaxa 2845, 1–174.

Hoffmann, B.D., 2000. Changes in ant species composition and community organisation along grazing gradients in semi-arid rangelands of the Northern Territory. Rangeland Journal 22, 171–189.

Hoffmann, B.D., 2003. Responses of ant communities to experimental fire regimes on rangelands in the Victoria River District of the Northern Territory. Austral Ecology 28, 182–195.

Hoffmann, B.D., Andersen, A.N., 2003. Responses of ants to disturbance in Australia, with particular reference to functional groups. Austral Ecology 28, 444–464.

Hoffmann, B.D., Griffiths, A.D., Andersen, A.N., 2000. Responses of ant communities to dry sulfur deposition from mining emissions in semi-arid tropical Australia, with implications for the use of functional groups. Austral Ecology 25, 653–663.

Hutchinson, K.J., King, K.L., 1980. The effects of sheep stocking level on invertebrate abundance, biomass and energy utilization in a temperate, sown grassland. Journal of Applied Ecology 17, 369–387.

Kaspari, M., 1993. Body size and microclimate use in Neotropical granivorous ants. Oecologia 96, 500–507.

Kaspari, M., Weiser, M.D., 1999. The size-grain hypothesis and interspecific scaling in ants. Functional Ecology 13, 530–538.

Lobry de Bruyn, L.A., 1999. Ants as bioindicators of soil function in rural environments. Agriculture, Ecosystems and Environment 74, 425–441.

McArthur, A.J., 2007. A key to *Camponotus* Mayr of Australia. In: Snelling, R.R., Fisher, B.L., Ward, P.S. (Eds.), Advances in Ant Systematics (Hymenoptera: Formicidae). , 80th ed. American Entomological Institute, Gainesville, pp. 290–351.

Read, J.L., Andersen, A.N., 2000. The value of ants as early warning bioindicators: responses to pulsed cattle grazing at an Australian arid zone locality. Journal of Arid Environments 45, 231–251.

Roe, P.A., Mulligan, D.R., Bell, L.C., 1996. Environmental management of coal mines in the Bowen Basin, central Queensland. In: Mulligan, D.R. (Ed.), Environmental Management in the Australian Minerals and Energy Industries: Principles and Practices. University of New South Wales Press, Sydney.

Schneider, K.E., 2004. Response of Ant Communities to Vegetation Clearing and Habitat Fragmentation in Central Qld. Doctor of Philosophy Thesis, University of South Australia.

Shattuck, S.O., 1999. Australian Ants: Their Biology and Identification. CSIRO, Collingwood.

Shattuck, S.O., Barnett, N., 2010. Ants down under. CSIRO Australia. Available at: http://anic.ento.csiro.au/ants/ (accessed 12.01.10).

Simon, B.K., 2010. New taxa, nomenclatural changes and notes on Australian grasses in the tribe Paniceae (Poaceae: Panicoideae). Austrobaileya 8, 187–221.

Smyth, A., Friedel, M., O'Malley, C., 2009. The influence of buffel grass (*Cenchrus ciliaris*) on biodiversity in an arid Australian landscape. The Rangeland Journal 31, 307–320.

Woinarski, J.C.Z., Andersen, A.N., Churchill, T.B., Ash, A.J., 2002. Response of ant and terrestrial spider assemblages to pastoral and military land use, and to landscape position, in a tropical savanna woodland in northern Australia. Austral Ecology 27, 324–333.

York, A., 2000. Long-term effects of frequent low-intensity burning on ant communities in coastal blackbutt forests of southeastern Australia. Austral Ecology 25, 83–98.