ANT COMMUNITY VARIATION WITH REHABILITATION AND MANAGEMENT HISTORY ON A SAND MINE AT NORTH STRADBROKE ISLAND, SOUTH-EAST QUEENSLAND

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Ant communities at Bayside Mine on North Stradbroke Island were examined as bioindicators of rehabilitation success to provide further information on ecosystem health compared to that which is determined by vegetation monitoring. Three distinct assemblages were collected, with the ant fauna at unmined eucalypt forests characteristic of such habitats, with many arboreal, litter-dwelling and shade-preferring species. The community composition of ants at an unburnt 30-year old rehabilitated forest resembled these unmined reference forests, although abundance, species richness and diversity were intermediate between reference sites and younger rehabilitation areas. An adjacent 30-year old rehabilitated forest exposed to wildfire was dissimilar to all sites, likely due to an incursion of the highly competitive pest ant, *Pheidole megacephala.* This species has been found in rehabilitation sites on the island previously and is thought to prefer areas with established vegetation where the microclimate at ground level has high humidity and lower temperature. Vegetation data from this study supports this suggestion, with a high understorey foliage projective cover and ground vegetation at this site compared to a paired adjacent unburnt site where the pest ant was absent. Ant communities at four 20-year old rehabilitated sites were similar to each other, regardless of management history, and contained mainly generalist species suggesting they were still recovering from the recent disturbances of management practices. Composition patterns, in relation to disturbance, were similar to previous research conducted on the island.

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INTRODUCTION

Sand and mineral mining has occurred on North Stradbroke Island since the early 1950s and, as per legislative requirements, rehabilitation has been progressively carried out in disturbed post-mining areas. Subsequently, monitoring is conducted to determine whether rehabilitated areas are progressing towards achieving the agreed completion criteria goals as required for eventual relinquishment of the land. Monitoring of mined areas of the island focus on vegetation parameters, soil physico-chemical conditions and landform stability, as well as endangered vertebrates (Queensland EPA 2007a); however, the examination of other faunal components is largely lacking. This is not surprising considering that vegetation is the only biotic component typically required to be detailed in mine site Environmental Plans (Queensland EPA, 2007b).

In Australia, ants have been widely used as biological indicators ('bioindicators') of mine site rehabilitation as a tool to reflect environmental health (Jackson & Fox, 1996; Majer & Nichols, 1998; extensive review in Hoffmann & Andersen, 2003; Nichols & Nichols, 2003). Ants are described as suitable bioindicators because they are widely abundant and species rich, relatively easy to sample and identify, sensitive to environmental change and involved with many functional components of the entire ecosystem (Majer, 1983; Andersen, 1990). As such, by examining ant community descriptors (such as species richness, abundance, diversity, evenness and dominance) and species composition, predictable patterns of ant recolonisation and response to disturbance have been described (Hoffmann & Andersen, 2003) and can be used to assess rehabilitation success.

A study on ants as bioindicators of mine rehabilitation assessment was conducted on North Stradbroke Island almost three decades ago (Majer, 1985) and found the pest ant *Pheidole megacephala* at three rehabilitation sites. This introduced ant (commonly called the African big-headed ant or coastal brown ant) is listed as one of the world's worst invasive species (Lowe et al., 2000). It is a major threat to biodiversity, as it is able to displace native ants and other invertebrate fauna (Hoffmann & Parr, 2008), as well as being detrimental in agricultural cropping systems, and causing annoyance and minor damage in man-made structures (Wetterer, 2007). Globally, *P. megacephala* is an alien species in approximately 50 countries, with extensive establishment throughout the Pacific Islands (ISSG, 2011). Within Australia, the ant is found along the eastern coast (widespread in Brisbane and south-east Queensland), as well as in and around Perth and Darwin (Burwell, 2007).

The two main objectives of this research were: 1) to examine ant community descriptors and composition to assess the rehabilitation at Bayside Mine and to provide deeper understanding of ecosystem health than that determined by vegetation monitoring alone; and 2) to investigate the distribution of *P. megacephala* on highly disturbed mined areas of North Stradbroke Island. Specifically, this study examined unmined native forest sites, as well as 20- and 30-year old rehabilitation areas.

MATERIALS AND METHODS

STUDY LOCATION AND SITES

Research was conducted on North Stradbroke Island in, or adjacent to, Bayside Mine rehabilitation areas (Figure 1). Native vegetation in the area is dominated by *Eucalyptus racemosa* subsp. *racemosa, E. planchoniana, E. pilularis, Corymbia gummifera* and *C. intermedia* (Regional ecosystem types 12.2.6 and 12.2.10; DERM, 2011), typically with a grass, heath or fern understorey (Stephens & Sharp, 2009). Species of *Acacia* and *Callitris* are also common in the upperstorey, with *Monotoca*, *Leucopogon* and *Elaeocarpus reticulatus* present in the midstorey.

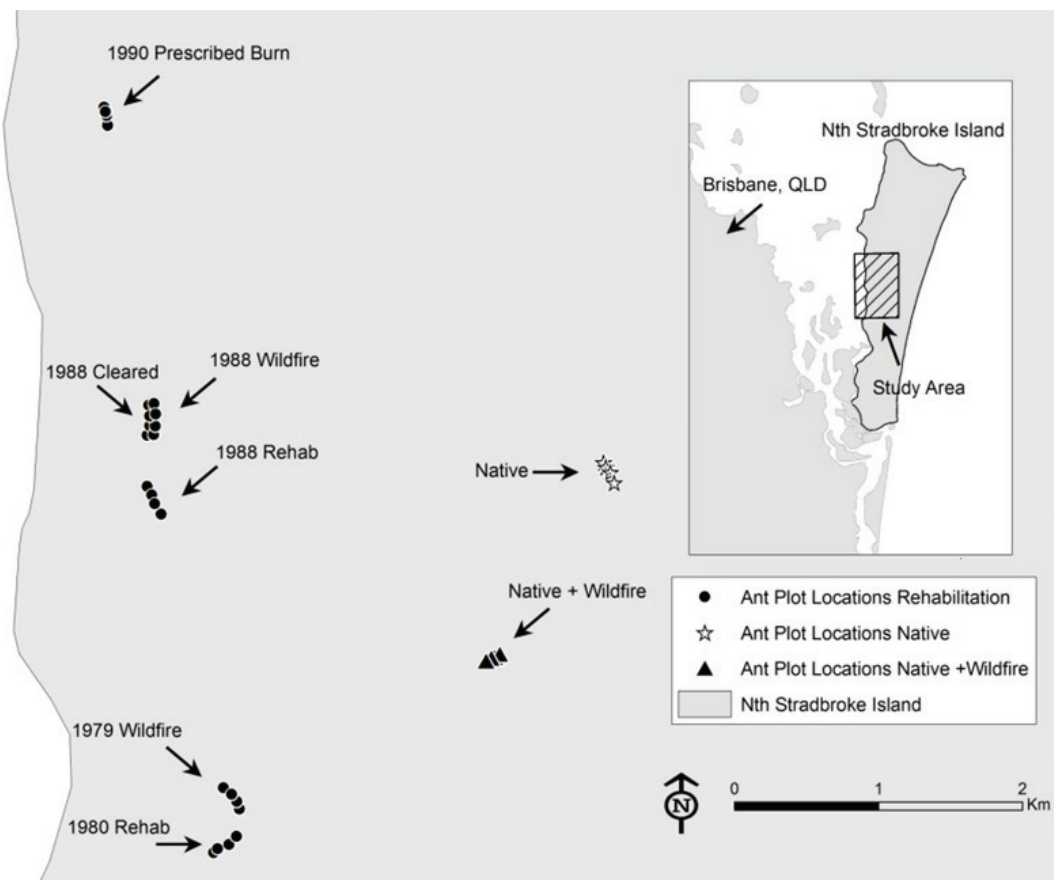


FIG. 1. Location and proximity of rehabilitated sites (1990 Prescribed Burn, 1988 Cleared, 1988 Wildfire, 1988 Rehab, 1979 Wildfire, 1980 Rehab) and reference sites (Native, Native + Wildfire) on North Stradbroke Island.

TABLE 1. The rehabilitation and disturbance history of study sites at North Stradbroke Island. Site names detailed here are used for the remainder of the tables and text, and site codes are used in the figures. Site names were determined by the year of rehabilitation (if relevant) and final disturbance type.

	Site names	Site code	Month and year of:			
			Rehabilitation	**Selective clearing**	**Prescribed burning**	**Uncontrolled fire**
Reference sites	Native	N	-	-	-	None recorded*
	Native+Wildfire	NW	-	-	-	Dec-Feb 2001‡
30-year old rehabilitation	1980 Rehab	80R	Nov 1980	-	-	-
	1979 Wildfire	79W	Dec 1979	-	-	Dec-Feb 2001‡
20-year old rehabilitation	1988 Rehab	88R	Feb 1988	-	-	-
	1988 Cleared	88C	Jun 1988	Apr 2007	-	-
	1990 Prescribed burn	90P	Sept 1990	Dec 2006	Jun 2007	-
	1988 Wildfire	88W	Feb 1988	Apr 2007	-	May 2007

Mine records do not provide details on the occurrence of fire (*) or details of an exact date (‡).

Eight sites on the Sibelco Australia Limited mining lease, incorporating Bayside Mine, were examined. These included two unmined native eucalypt forests and two mined sites rehabilitated in 1979 or 1980 (broadly termed '30-year old rehabilitation'), with one of each of these paired sites burnt by an intense wildfire in 2001. Four mined sites rehabilitated in 1988 or 1990 ('20-year old rehabilitation') and exposed to different management practices were also examined. In this area, vegetation species that had become dominant components of the rehabilitation (such as *Acacia concurrens* and *Allocasuarina littoralis*) were to be selectively cleared and subjected to a prescribed low intensity fire to increase understorey flora diversity. However, this combination of management procedures was only successful at one site. Unusually hot weather prohibited burning at one cleared site, and another site was exposed to an intense wildfire after clearing. The fourth site remained uncleared and unburnt. Details on site characteristics are given in Table 1.

ANT SAMPLING AND HABITAT CHARACTERISATION

At each site, four replicate plots were positioned at a minimum distance of 50 m apart. Independent replication of sites was not possible, as similarly-aged sites with consistent rehabilitation methods and management techniques were not available. Therefore, the term 'replicate' in this paper refers to pseudoreplication of sampling plots within each site. Three complementary sampling methods were used at each plot, which were sampled between the 24th and 31st March 2009. At each sampling plot, a 10 m x 10 m grid of pitfall traps (25 traps) was configured into five columns of five traps with 2.5 m spacing (100 pitfall traps per site). Pitfall traps consisted of a 50 mL centrifuge tube (30 mm diameter) filled with approximately 20 mL of propylene glycol to act as a killing/preserving agent and to minimise evaporation. This solution was used as an alternative to ethylene glycol or alcohol-based mixtures as it is less toxic to vertebrates (Bestelmeyer et al., 2000). Traps were inserted into the ground as per Majer (1978), utilizing a small length of polyethylene pipe hammered into the ground around a removable pin to act as a receptacle for the pitfall trap. Traps were opened immediately after insertion and operated for 6 days.

Hand collections were conducted for 30 minutes at each replicate plot (therefore, 2 hours per site) in fine, warm weather between the hours of 8.30 a.m. and 4 p.m. Collections were made on vegetation and in/under fallen wood, litter or other ground debris. Four litres of litter and underlying humus was collected at each plot (thus, 16 L per site) from several areas of the grid. Within 3 hours of collection, samples were transported to the laboratory and ants extracted by Berlese funnels over 5 days.

A 50 m transect was positioned approximately 15 m from each ant sampling plot (4 per site) and habitat variables that may influence ant communities were recorded. At 1 m intervals, ground cover (rock, leaf litter, live vegetation, bare ground, woody debris or other) was recorded, as well as understorey (below 2 m) foliage projective cover (FPC) and overstorey FPC (above 2 m). In 2 m x 2 m quadrats randomly positioned along the transect, plant species abundance, leaf litter depth and woody debris volume were recorded. A 50 m x 10 m plot located to the outer side of the transect was used to record the species and abundance of trees greater than 2 m. Additional descriptions of replicate and site characteristics were noted, including aspect, vegetation health, soil descriptors, and dominant vegetation in each vertical stratum (canopy, subcanopy, midstorey and understorey).

ANT IDENTIFICATION AND STATISTICAL ANALYSIS

Ants were identified to genera following Shattuck (1999) and then to morphospecies (Andersen, 2000; Burwell, 2007; McArthur, 2007; Shattuck & Barnett, 2007; Shattuck, 2008; Shattuck, 2009; Shattuck & Barnett, 2010; Heterick & Shattuck, 2011). For ease of reading the term 'species' will be used instead of morphospecies for the remainder of this paper. As the taxonomy of Australian ants is incomplete, undescribed species were given an identification code applicable to this study only. A subset of species was identified by Dr Chris Burwell, senior curator of insects at the Queensland Museum, for verification of identification. Alates (winged reproductive castes) were omitted from analyses as their origin is unknown.

Ant community descriptors were calculated for each site, including species richness (the number of species collected), abundance (number of individual ants), Simpson's reciprocal diversity (a measure of the range and abundance of species; Magurran, 2004), Simpson's evenness index (a measure of similarity between species abundance values; Magurran, 2004), and the Berger-Parker index (a measure of dominance; Magurran, 2004). To determine body size, a sample of minor workers from each species was measured from clypeus to the distal tip of the gaster and with the head and gaster at a relaxed position of approximate 30-45° below horizontal. Ants were then categorized as small (<3 mm), medium (>3 – 6 mm) or large (>6 mm).

PRIMER v6 (Clarke & Gorley, 2006) was used to compute multivariate analyses, including non-metric multidimensional scaling ordination, with similarity between plots determined by cluster analysis. Data from all sampling methods was transformed by log(x+1) and used Bray Curtis similarities. The BIOENV function of PRIMER was employed to determine which habitat variables best explained the observed ant species collected during this study. Prior to BIOENV calculations, pairs of habitat variables were examined by regression analysis to eliminate the use of interrelated variables. Differences in the habitat variables between sites were tested by t-tests and ANOVAs (followed by post hoc testing with Tukey's HSD) on plot averages using STATISTICA v10.

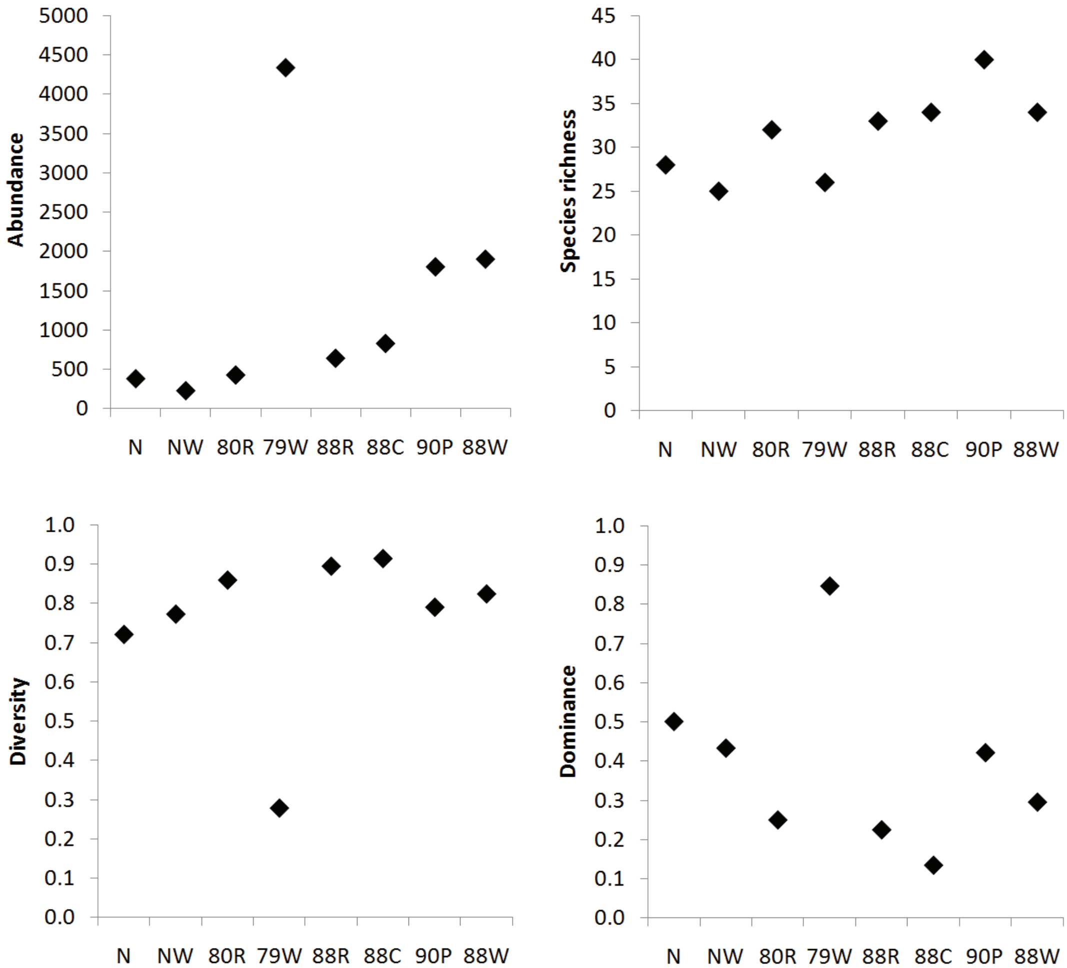
RESULTS

COMMUNITY DESCRIPTORS AND COMPOSITION

A total of 78 species from 32 genera were collected. *Iridomyrmex* and *Polyrhachis* were the most speciose genera with eight species each; the former genus was found predominantly in the 20-year old rehabilitated sites and the latter in the native vegetation sites. Of the 10,579 specimens captured, 3,676 were *Pheidole megacephala* at the 1979 Wildfire site. Site species richness was low at this site (Figure 2), similar to the two native vegetation sites. The 1979 Wildfire site was also markedly dissimilar to the other sites in terms of diversity, dominance and evenness of ants due to the skewed population distribution of *P. megacephala*.

With the exception of a single specimen for each genus, no *Melophorus* or *Iridomyrmex* were found in the native or old rehabilitation sites (Table 2). Ants with a small body size ($\geq$ 3 mm) were more prevalent in rehabilitation plots (34 species) compared to reference sites (7). Most species of *Polyrhachis* were primarily collected at the native sites (Table 3), with the exception of *Polyrhachis ammon,* which was common at all sites except the 1979 Wildfire site. Thirteen species tended to increase in abundance with disturbance, including *Camponotus* sp. NSI2, *Cardiocondyla nuda*, *Iridomyrmex* (3 species), *Melophorus* species (2), *Monomorium fieldi*, *Pachycondyla (Brachyponera) lutea*, *Pheidole* species (2), *Tapinoma minutum* and *Tetramorium thalidum*. In contrast, only *Pachycondyla* sp. NSI2 appeared to decrease with disturbance.

Non-metric multidimensional scaling ordination depicted that the 1979 Wildfire plots were distinctly separate from all other plots (Figure 3) and cluster analysis confirmed that this pattern of differences was statistically significant ($p<0.05$). A comparable depiction was also computed when *P. megacephala*



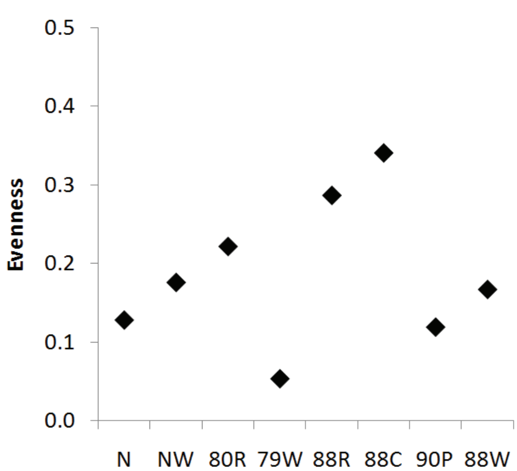


FIG. 2. Site values for ant community descriptors, including abundance (number of individuals collected), species richness (number of species), Simpson's reciprocal diversity (where 0 = no diversity and 1 = highly diverse), Berger-Parker dominance index (0 = no single species dominant, 1 = one species highly dominant) and Simpson's evenness index (0 = individual species abundances not similar, 1 = species abundances very similar). Sites are presented from left to right on the assumption of least to most disturbed, taking into consideration (in order): 1) rehabilitation age; 2) number of disturbances; and 3) time since last disturbance/s. Site codes are detailed in Table 1.

TABLE 2. Presence and abundance of ants at sites sampled by pitfall traps (left or sole value), litter samples (right value) and hand collections (*). Ant sizes are categorized as small ('S'; ≤3 mm), medium ('M'; >3 – 6 mm) or large ('L'; > 6mm). In the far right column, taxonomic details are given for the corresponding species of ants detailed in Majer (1985) and include identifications updated by J. Majer (personal communication) in parentheses. Species that were not collected during the previous study are depicted with '-', and '†' portrays that although the genus was present in the lists of Majer (1985), it was not possible to determine if the species was consistent with taxa collected during the current study. Site codes are detailed in Table 1.

	Size	N	NW	80R	79W
Acropyga myops	S			0/2	
Aphaenogaster longiceps	M	178/11*			
Aphaenogaster pythia	M	1	*		
Camponotus aeneopilosus	L	3*	4*	1*	
Camponotus claripes	M	*	*		
Camponotus gasseri	L				*
Camponotus humilior	M	3	8*	5	
***Camponotus* sp. NSI1**	M				
***Camponotus* sp. NSI2**	L	*		2	
Cardiocondyla nuda	S				
***Carebara* sp. NSI1**	S			9/2	4
Colobostruma unicorna	S				3
***Crematogaster* sp. NSI1**	M	0/1			
***Crematogaster* sp. NSI2 (*queenslandica* grp)**	S			2	1
***Crematogaster* sp. NSI3 (grp C)**	M	23*	96*	8*	
***Hypoponera* sp. NSI1**	M			9/95	1/35
***Hypoponera* sp. NSI3**	S				3
Iridomyrmex bicknelli	M				
Iridomyrmex calvus	S				
Iridomyrmex discors	M				
Iridomyrmex dromus	S				
Iridomyrmex innocens	M				
Iridomyrmex rubriceps	L				
***Iridomyrmex* sp. NSI1**	S				
***Iridomyrmex* sp. NSI2**	M			1	
Leptomyrmex varians	L	9*	4*	*	
Mayriella abstinens	S				46/33
***Melophorus* sp. NSI1 (grp D)**	M				
***Melophorus* sp. NSI3 (*aeneovirens* grp)**	L				

	88R	88C	90P	88W	Majer (1985) identifications (2011 revised identifications)
Acropyga myops					-
Aphaenogaster longiceps					-
Aphaenogaster pythia					*Aphaenogaster longiceps* (*A. pythia*)
Camponotus aeneopilosus	*	*	2*		*Camponotus(innexus* gp.) sp. 1 (*C.aeneopilosus)*
Camponotus claripes					†
Camponotus gasseri	*				†
Camponotus humilior					†
***Camponotus* sp. NSI1**	1	1	2		†
***Camponotus* sp. NSI2**	*	1	7	14	†
Cardiocondyla nuda			71/2*	67*	*Cardiocondyla*sp. 1 (*C.'nuda'*)
***Carebara* sp. NSI1**	1/2	2/2	½	1	-
Colobostruma unicorna		3/3			-
***Crematogaster* sp. NSI1**	21*	15*		7/1	†
***Crematogaster* sp. NSI2 (*queenslandica* grp)**	22/1*		10/1		*Crematogaster* sp. 3 (*C.* subgenus *orthocrema*)
***Crematogaster* sp. NSI3 (grp C)**			14*		†
***Hypoponera* sp. NSI1**			1/1		†
***Hypoponera* sp. NSI3**	*				†
Iridomyrmex bicknelli	1	103*	77*	516*	*Iridomyrmex* (E) sp. 2 (*I. bicknelli*)
Iridomyrmex calvus				16	†
Iridomyrmex discors		4	2	21*	*Iridomyrmex* (D) sp. 2 (*I. discors*)
Iridomyrmex dromus	3	1*	81*	48*	†
Iridomyrmex innocens	1				†
Iridomyrmex rubriceps			*	1	*Iridomyrmex* (J) sp. 1 (*I. rubriceps*)
***Iridomyrmex* sp. NSI1**	14*		9		†
***Iridomyrmex* sp. NSI2**					†
Leptomyrmex varians					*Leptomyrmex* sp. 4
Mayriella abstinens	0/1				-
***Melophorus* sp. NSI1 (grp D)**			3		†
***Melophorus* sp. NSI3 (*aeneovirens* grp)**	4*	6*	11	8*	†

	Size	N	NW	80R	79W
***Melophorus* sp. NSI4 (grp B)**	M				
***Melophorus* sp. NSI6 (grp H)**	M				
***Melophorus* sp. NSI7 (*mjobergi* grp)**	S				
***Melophorus* sp. NSI8 (*bruneus* grp)**	S/M	1			
Monomorium fieldi	S	*		9	39*
***Monomorium* sp. NSI1**	S				
***Monomorium* sp. NSI3**	S	11/10	4/4	2	2/2
Monomorium tambourinense	S			1	
Myrmecia brevinoda	L	*			
Myrmecia fulviculis	L	*		*	
Myrmecina inaequala	S	5	1		
Notoncus capitatus	M	18*	33*	36/2*	
***Nylanderia* sp. NSI3 (*obscura* grp)**	S				
***Nylanderia* sp. NSI5 (*vaga* grp)**	S	2		4	79/23*
***Ochetellus glaber* grp**	S				1*
***Pachycondyla* (*Bothroponera*) sp. NSI1**	L		2	1	1*
Pachycondyla* (*Brachyponera*) *lutea	M			1	
***Pachycondyla* sp. NSI2**	L	6	3	5	*
***Paraparatrechina* sp. NSI1 (*minutula* grp)**	S			0/10	18/11*
Pheidole megacephala	S				3330/339*
***Pheidole* sp. NSI1 (grp A)**	S		7	18	
***Pheidole* sp. NSI2 (grp D)**	S				
***Pheidole* sp. NSI4 (grp E)**	S				2
***Pheidole* sp. NSI7**	S				
***Plagiolepis* sp. NSI1**	S	3			
Polyrhachis ammon	L	*	1*	1*	
Polyrhachis australis	M		*		
Polyrhachis daemeli	L	*	*		
Polyrhachis hookeri	M	*			

	88R	88C	90P	88W	Majer (1985) identifications (2011 revised identifications)
***Melophorus* sp. NSI4 (grp B)**				24	†
***Melophorus* sp. NSI6 (grp H)**		4	7	1	†
***Melophorus* sp. NSI7 (*mjobergi* grp)**	6	11	31	70	†
***Melophorus* sp. NSI8 (*bruneus* grp)**					†
Monomorium fieldi	10/1	97/1*	739/16*	547/3*	?*Monomorium*sp. 5
***Monomorium* sp. NSI1**		2	6	5	†
***Monomorium* sp. NSI3**			4		†
Monomorium tambourinense					*Chelaner* sp. new (67) (*Monomorium tambourinense*)
Myrmecia brevinoda				*	-
Myrmecia fulviculis	2*	5*	2	5*	-
Myrmecina inaequala					-
Notoncus capitatus	17*	13*		9*	*Notoncus* sp. 2 (*N. capitatus*)
***Nylanderia* sp. NSI3 (*obscura* grp)**	140*	20	2	128*	†
***Nylanderia* sp. NSI5 (*vaga* grp)**		2		*	†
***Ochetellus glaber* grp**		3*	3/1*		*Iridomyrmex* (A) sp. 2 + sp. 3 (*Ochetellus glaber* grp)
***Pachycondyla* (*Bothroponera*) sp. NSI1**					-
Pachycondyla* (*Brachyponera*) *lutea	4/1*	3*	14/1*	5/3*	*Brachyponera lutea*
***Pachycondyla* sp. NSI2**	1	*	1		*Mesoponera* sp. 1 (*Pachycondyla australis*)
***Paraparatrechina* sp. NSI1 (*minutula* grp)**	25/38*	1/101*	24/1*	15/2*	†
Pheidole megacephala					*Pheidole megacephala*
***Pheidole* sp. NSI1 (grp A)**		10*			†
***Pheidole* sp. NSI2 (grp D)**	0/30		217/3*		†
***Pheidole* sp. NSI4 (grp E)**	59/1	107/5	110/5*	75/2	†
***Pheidole* sp. NSI7**		1			†
***Plagiolepis* sp. NSI1**					-
Polyrhachis ammon	1*	14/8*	10*	1/1*	*Polyrhachis ammon*
Polyrhachis australis					-
Polyrhachis daemeli					-
Polyrhachis hookeri			*		*Polyrhachis hookeri*

	Size	N	NW	80R	79W
Polyrhachis mjobergi	M	1*		*	
Polyrhachis phryne	M		*		
Polyrhachis semiaurata	L	1	*		
Polyrhachis tubifera	M		1		
***Ponera* sp. NSI1**	S				0/1
Prionopelta robynmae	S				28
Proceratium pumilio	S			0/2	
Rhytidoponera metallica	M/L	42*	19*	22/7*	
***Rhytidoponera* sp. NSI2**	L	8*	3/1*	2	
Rhytidoponera victoriae	M			102/3*	
***Solenopsis* (*Diplorhoptrum*) sp. NSI1**	S			7/3	13/37
***Stigmacros* sp. NSI1 (*spinosa* grp)**	S			4/6*	109/9
***Stigmacros* sp. NSI2**	S	1	0/1	1/19	59/54*
***Stigmacros* sp. NSI4**	S				
Strumigenys deuteras	S			1	0/7
Strumigenys ferocior	S				1
Tapinoma minutum	S				18
Technomyrmex antonii	M	*	1		3
Technomyrmex furens	M		*	*	
Tetramorium thalidum	M	2	5		

TABLE 3. Trends in the local distribution of ant genera and species.

	Native sites	**Native and 1979/80 rehab sites**	**1979/80 rehab sites**	**1979/80 rehab and 1988 rehab sites**	**1988 rehab sites**
Only or predominantly found	*Aphaenogaster longiceps* *Aphaenogaster pythia* *Leptomyrmex varians* *Myrmecina inaequala* *Polyrhachis* spp. (6) *Rhytidoponera* sp. NSI2	*Camponotus humilior* *Pachycondyla (Bothroponera)* sp. NSI1	*Hypoponera* spp. (2) *Strumigenys deuteras*	*Carebara* sp. NSI1 *Paraparatrechina* sp. NSI1 (*minutula* grp) *Solenopsis* (*Diplorhoptrum*) sp. NS1 *Stigmacros* spp. (3) *Strumigenys ferocior* *Tapinoma minutum*	*Iridomyrmex* spp. (7) *Melophorus* spp.(5) *Nylanderia* sp. NSI (*obscura* grp) *Pheidole* spp (2)

	88R	88C	90P	88W	Majer (1985) identifications (2011 revised identifications)
Polyrhachis mjobergi					-
Polyrhachis phryne					-
Polyrhachis semiaurata				2	*Polyrhachis semiaurata*
Polyrhachis tubifera					-
***Ponera* sp. NSI1**		0/1	0/2		-
Prionopelta robynmae		0/1	2		*Prionopelta* sp. 1 (*P. opaca*)
Proceratium pumilio					-
Rhytidoponera metallica	4*	36/15*	12/2*	34/1*	*Rhytidoponera* (*metallica*) grp.
***Rhytidoponera* sp. NSI2**				3*	-
Rhytidoponera victoriae	22/5*	50*	5	3/7*	?*Rhytidoponera*sp. 13
***Solenopsis* (*Diplorhoptrum*) sp. NSI1**	16/80	3/24*	13/109	7/10	*Solenopsis* sp. 1
***Stigmacros* sp. NSI1 (*spinosa* grp)**	8/25*	3/1*	7/18	4/38*	†
***Stigmacros* sp. NSI2**	2		3/1	0/3	†
***Stigmacros* sp. NSI4**	0/7				†
Strumigenys deuteras					†
Strumigenys ferocior			4	1	†
Tapinoma minutum	3*	32	6	59/2	†
Technomyrmex antonii			6		*Technomyrmex* sp. 2
Technomyrmex furens					-
Tetramorium thalidum	6*	33/12*	65*	43/27*	-

was omitted from analysis. The 1980 Rehab plots were most similar to the native plots, although not significantly so. These unmined native plots were significantly similar to each other, as were all 20-year old rehabilitation plots.

DISTRIBUTION OF *P. MEGACEPHALA*

The 1979 Wildfire site was the only site where *P. megacephala* was collected or observed. Ants with a small body size tended to coexist with the pest ant, with 19 of the 24 native species collected measuring less than 3 mm in length. The abundance of *P. megacephala* at the 1979 Wildfire site was substantially higher than the total number of native ants collected in all other sites. All individual pitfall traps at the infested site contained *P. megacephala*, with several traps deficient of other ant species.

Trends in individual species at sites grouped by their mining and rehabilitation history revealed that the 1979 Wildfire site frequently showed disparities with the other sites. For example, *Camponotus humilior* and *Crematogaster* sp. NSI3 (group C) were not collected at this site, but were captured at the 1980 Rehab and native sites. Furthermore, *Monomorium fieldi*, *Pachycondyla* sp. NSI2, *Paraparatrechina* sp. NSI1 (*minutula* group) and *Solenopsis* (*Diplorhoptrum*) sp. NSI1 were collected at abundances more similar to the 20-year old rehabilitation sites when compared to the 1980 Rehab or native sites. There were increased numbers of *Mayriella abstinens*, *Camponotus gasseri*, *Hypoponera* sp. NSI3, *Nylanderia* sp. NSI5 (*vaga* group), *Prionopelta robynmae*, *Stigmacros* sp. NSI1 (*spinosa* group) and *Stigmacros* sp. NSI2 in the 1979 Wildfire compared to all other sites. In contrast, the 1979 Wildfire site was the only site sampled in this

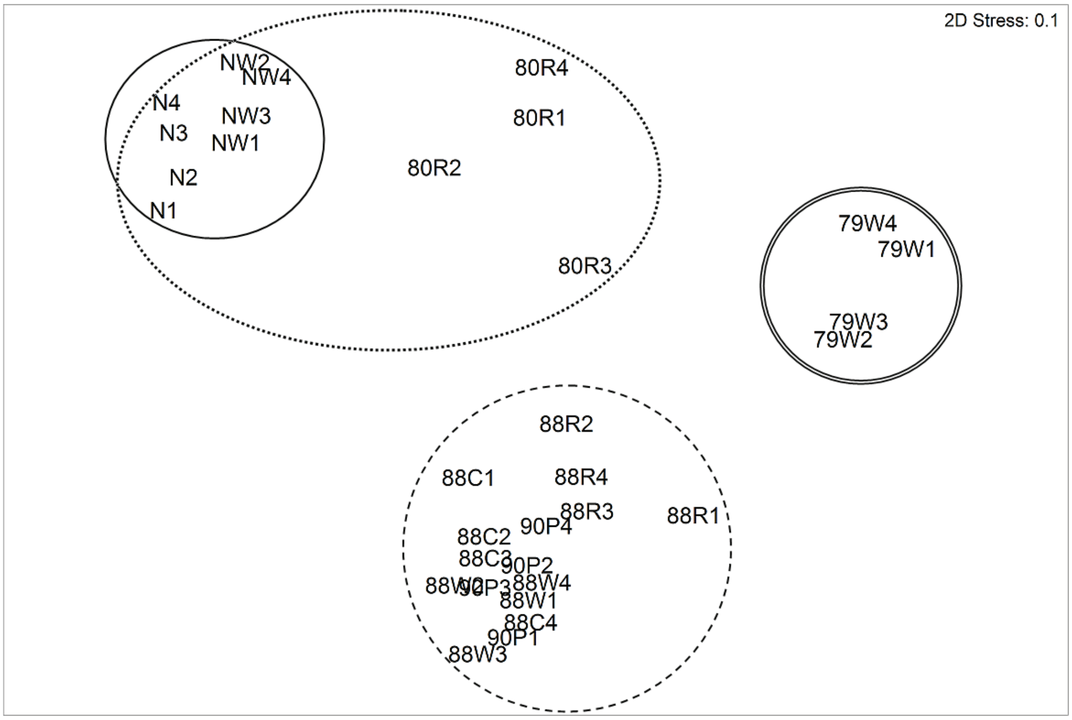


FIG. 3. Separation of ant communities with varying rehabilitation and management history depicted by ordination of plots using non-metric multidimensional scaling. Plots within the same circle are 65% similar (bold line), 48% similar (fine solid line), 43% similar (dashed line) and 30% similar (dotted line) according to cluster analysis. Data from pitfall traps, hand collections and litter samples was transformed by log(x+1) and used a Bray Curtis resemblance matrix. Site codes are detailed in Table 1.

study where species of *Polyrhachis* and *Rhytidoponera* were not collected; *P. ammon* and *R. metallica* were common to all other sites but absent at this site.

INFLUENCE OF HABITAT VARIABLES

When considering habitat variables, BIOENV calculated that 55.2% of ant community composition (transformed by log(x+1) with a Bray Curtis similarity matrix) was explained by litter depth and this was the greatest value for all variables and combinations examined. Examination of the habitat data illustrated some differences between the 30-year old rehabilitation sites (Figures 4 and 5). Specifically, understorey FPC was lower at 1980 Rehab compared to the 1979 Wildfire site (two-sample t-test: $t = -4.75$, $df = 4$, $p = 0.0090$), although the overstorey FPC was similar. At the unburnt site, there was a greater cover of woody debris on the ground ($t = 3.8996$, $df = 4$, $p = 0.0175$), but total site vegetation richness was lower. Vegetation cover was greater at the 1979 Wildfire site, although both these sites had <10% total ground cover. When examining all study areas, the uncleared sites had a higher proportion of the ground covered by leaf litter compared to sites that had been selectively cleared (Tukey's HSD test, $p < 0.05$), while these latter sites had higher proportions of bare ground (significant for the 1988 Wildfire site; Tukey's HSD test, $p < 0.05$).

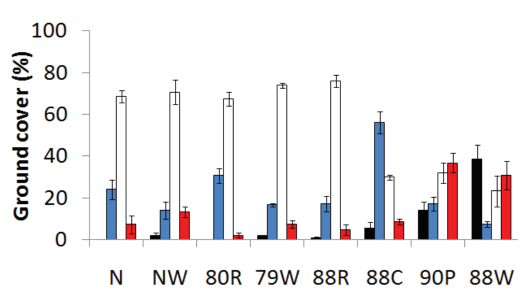


FIG. 4. Mean percentage of ground cover constituents at each site, including bare ground (black bars), woody debris (blue), leaf litter (white) and live vegetation (red). Error bars show standard error of the mean. Site codes are detailed in Table 1.

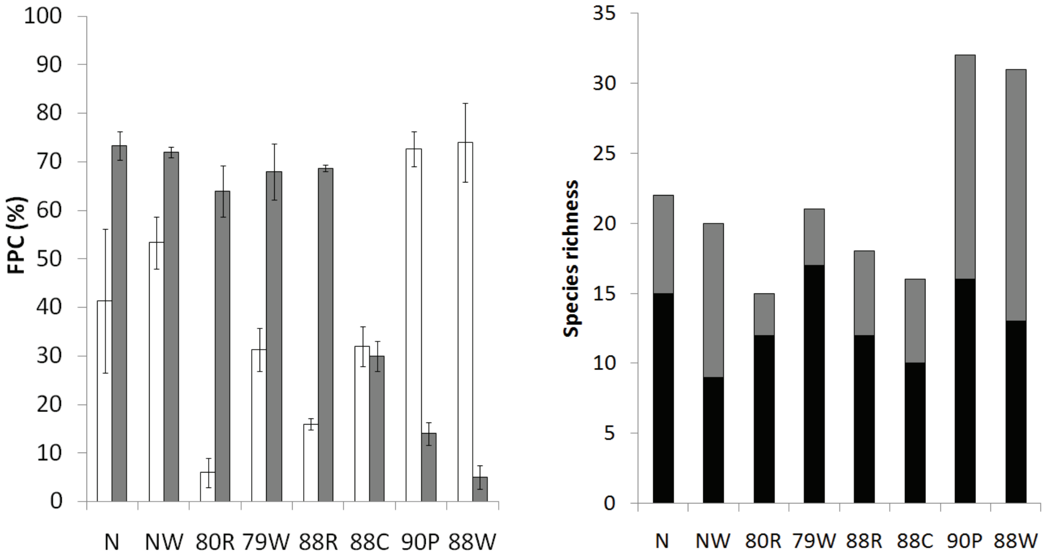


FIG. 5. Vegetation variables at each site including a) mean foliage projective cover (FPC) of understorey (0-2 m; white) and overstorey (>2 m; grey); and b) total plant species collected in quadrats at each site (black + grey), incorporating tree richness (black section). Site codes are detailed in Table 1.

COMPARISON TO STUDY BY MAJER (1985)

Of the 78 species collected during this study, 21 were also collected in the earlier study and an additional two species were tentatively identified as taxa collected previously (Majer 1985; revised identifications by J. Majer, personal communication). Twenty species collected during the current study were not captured in the earlier research, while 35 species could not be determined as equivalent to those collected by Majer (1985), despite the genus being collected at that time. Details of corresponding species and genera are given in Table 2. An additional five species were collected by Majer (1985) that were not collected during the current study, including *Cerapachys* sp. new (43) (revised in 2011 to *C. longitarsus*), *Epopostruma* sp. new, *Bothriomyrmex* sp. 1 (*Arnoldius* sp.), *Platythyrea* sp. 1 (*P. parallela*) and an undetermined Ponerine species.

DISCUSSION

Examination of the ant fauna at the study sites on North Stradbroke Island depicted three distinct assemblages. The ants that were characteristic of the native vegetation sites were typical forest inhabitants, such as *Aphaenogaster longiceps* (commonly called the forest funnel ant; Burwell, 2007) and species of *Leptomyrmex* (CSIRO Australia, 2011b), which typically nest in open or wet forests. Additionally, the leaf litter foraging *Myrmecina inaequala* (Shattuck, 2009) and arboreal foraging or nesting *Polyrhachis* species (Robson & Kohout, 2007) were common at the references sites.

In contrast, ants captured in the 20-year old rehabilitation sites tended to be generalist species, with no specific food or nesting preferences, including *Nylanderia obscura* and species of *Pheidole* and *Iridomyrmex* (Shattuck, 1999). Members of this latter genus, in addition to the thermophilic *Melophorus* species, prefer open areas and bare ground (Andersen et al., 2003), and were higher in abundance in the cleared rehabilitation sites. Similarly, many of the species and genera that increased with disturbance by management practices at the 20-year old rehabilitation sites were generalist ants with few resource limitations, such as *Monomorium fieldi*, *Tapinoma minutum*, *Tetramorium thalidum* (Shattuck, 1999; Andersen, 2000) and the naturalized tramp ant, *Cardiocondyla nuda* (Heinze et al., 2006; CSIRO Australia, 2011a). Interestingly, many species collected in the rehabilitation sites were small in size, which supports the suggestion that smaller species tend to be better colonisers with a high tolerance to disturbance, as observed previously in ants (McGlynn, 1999) and beetles (Niemelä et al., 2000).

The increase of generalist species at the 20-year old rehabilitation suggests that the sites are still recovering from the recent disturbances by management practices, or still influenced by the canopy dominance in the uncleared 1988 Rehab site. However, the ant communities collected at these sites were characterised by high species richness and diversity, as well as the presence of several specialised species, which is a common trend during the mid stages of ant recolonisation (Bisevac & Majer, 1999) and similar to the response of ants to comparable disturbances on unmined land (York, 2000; Parr et al., 2004; Gibb & Hjältén, 2007). Due to the lack of temporal replication of study sites, it is not possible to determine whether the ant fauna at 20-year old rehabilitation sites is likely to converge with the reference sites in the future; however, the similar composition of ants at these sites to those on unmined disturbed land suggests that convergence is not unrealistic.

The introduced and highly dominant *Pheidole megacephala* was collected only at the 1979 Wildfire site and is proposed to be the cause of the significantly different ant community composition at this site compared to all other sites, as well as the low evenness and diversity values. Although this renders an assessment of rehabilitation success at this site difficult, several points of interest are noted. Despite low species richness at the 1979 Wildfire site compared to the other rehabilitation sites, richness was not depressed to the same degree as found in other ant communities dominated by *P. megacephala* (Majer & de Kock, 1992; Heterick, 1997; Hoffmann et al., 1999; Vanderwoude et al., 2000; Wetterer, 2007; Hoffmann & Parr, 2008; Hoffmann, 2010). However, the high abundance of the pest ant compared to native ants was similar to levels recorded in such studies. Specifically, *P. megacephala* was 105 times more abundant than the total number of native ants collected at the 1979 Wildfire site, similar to a study near Darwin (Hoffmann et al., 1999), and contributed 88% of the total ants collected at the 1979 Wildfire site, comparable to infestations at Mount Coot-tha (Heterick, 1997).

Trends in species coexistence with *P. megacephala* observed at other research sites in south-east Queensland were also observed in the current study. For instance, an absence or decrease in the abundance of large ant species, such as *Rhytidoponera* species, *Polyrhachis* species, *Leptomyrmex varians* and *Camponotus humilior,* was found at the 1979 Wildfire site, as well as in previous research on North Stradbroke Island (Majer, 1985) and/or Mount Coot-tha (Heterick, 1997). Additionally, there was increased abundance of *Paraparatrechina*, *Stigmacros* and *Mayriella* species at the infested sites in both the current study and at Mount Coot-tha (Heterick, 1997). Heterick (1997) proposed that these ants are able to coexist with *P. megacephala* due to their small size and cryptic nature (that is, dwelling in woody debris, soil or leaf litter). This suggestion is supported by the current study, which found the majority of native ant species at the 1979 Wildfire site were less than 3 mm in length and foraged or nested in leaf litter or underneath ground debris. This pattern of large subordinate species being displaced by *P. megacephala*, while small cryptic ants are able to persist, was also observed in the Darwin study (Hoffmann et al., 1999). This is in line with the size-grain hypothesis suggesting that small ant species have a competitive advantage in complex habitats (such as leaf litter) compared to large species (Kaspari & Weiser, 1999; Farji-Brener et al., 2004), and has been observed with other highly dominant pest ants such as Argentine ants (Sarty et al., 2006).

Despite similar site attributes, identical rehabilitation methods and adjacent proximity to the infested site, *P. megacephala* was not found at the 1980 Rehab site. As this species is a ground disperser via colony "budding" (Wetterer, 2007), its dispersal may be limited compared to spreading by flight. More likely, the microclimate at the 1980 Rehab site may be less favourable due to the vegetation and habitat characteristics present, as a result of the absence of fire. Specifically, there was decreased vegetation ground cover and understorey FPC, which can result in less stable ambient temperatures and lower humidity (Willmer, 1982; Chen et al., 1993) and such microclimate variables have been shown to be correlated with the local distribution of *P. megacephala* (Greenslade, 1972; Majer, 1985; Hoffmann et al., 1999; Hoffmann & Parr, 2008).

In terms of rehabilitation assessment, the ant fauna at the 1980 Rehab site most resembled the reference sites, although differences persisted. This may, in part, be due to the now outdated techniques used 30 years ago to rehabilitate the site, which have improved in recent decades through research on restoration ecology. As inferior rehabilitation techniques tend to delay, rather than permanently impede, the recolonisation of ants at sand mines (Majer & Nichols, 1998), the ant fauna at the 1980 Rehab site may be expected to converge with those at the reference sites in the future. This suggestion is further supported by the intermediate values for community descriptors at this site compared to the reference sites and the younger rehabilitation sites.

Although replication of Majer's early work would have been valuable in assessing long-term trends of ant communities at rehabilitated mines, the lack of precise coordinates and undefined rehabilitation borders meant that sites could not be accurately ascertained and resurveyed during the current study. Noteworthy differences between the previous study and the current survey include differences in site selection (chronosequence analysis versus disturbance intensity/frequency gradient) and the influence of alternative rehabilitated areas of North Stradbroke Island (Amity Point and eastern dunes versus western dunes) despite similar vegetation types and regional ecosystem classifications (DERM, 2011) for all study areas.

Similarities between the two studies were apparent, such as ordination analysis depicting that the rehabilitated plots were significantly different to unmined reference plots, as were plots dominated by *P. megacephala*. Furthermore, litter depth was a major determinant of ant community composition in both studies. Many of the species found only at the reference sites in Majer (1985) and the current study were cryptic litter dwellers, woody debris nesters or arboreal foragers/nesters. Specifically, *Aphaenogaster longiceps*, *Leptomyrmex varians* (corresponding to *L*. sp. 4 in Majer, 1985) and *Polyrhachis hookeri* were found predominantly in the unmined reference sites in both Majer (1985) and the current study.

Using ants as bioindicators to assess mine rehabilitation and management practices on sites at Bayside Mine, North Stradbroke Island, found three distinct ant assemblages. The 1980 Rehab site was more similar in community composition to the reference sites compared to all other rehabilitation sites, and had intermediate values of species richness, abundance, diversity, dominance and evenness. Due to the incursion of *P. megacephala*, the 1979 Wildfire site did not exhibit this resemblance to reference sites. Additionally, the 20-year old rehabilitation sites were still influenced by the remaining dominant canopy cover (at 1988 Rehab) or the recent management practices aimed at remediating this dominance. The information provided in this paper has established valuable baseline data for the studied areas that can be used for continued spatio-temporal investigations. The use of a faunal bioindicator such as ant communities, as a complement to vegetation surveys, may provide sensitive measures of ecosystem health and recovery of rehabilitated mine sites on North Stradbroke Island.

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