Early and late colonizers in mine site rehabilitated waste dumps in the Goldfields of Western Australia

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We examined the abundance of reptile and mammal species on five rehabilitated waste dumps in the early successional stages in the mined area around Ora Banda in Western Australia and compared these data with species richness and abundance in adjacent undisturbed areas. Mammal species common in the undisturbed areas were also found in relatively high abundance on waste dumps, with the exception of *Pseudomys hermannsburgensis*. In contrast, not all reptile species in the adjacent undisturbed areas had colonized waste dumps. However, a high proportion of those reptile species that were caught on rehabilitated waste dumps were at lower numbers than in the adjacent undisturbed areas, indicating that they were slow colonizers. Reptiles *Underwoodisaurus milii*, *Heteronotia binoei* and *Pogona minor* and mammals *Mus musculus* and *Sminthopsis crassicauda* are among the early colonizing species that flourish in the developing ecosystem on waste dumps. Species able to exploit a diverse range of niches, tolerate open spaces, have a generalist diet and good dispersal capabilities are the early colonizers. In contrast, species with a specialist diet or micro-habitat requirements are slow to colonize rehabilitated waste dumps and will initially be represented in low numbers. We encourage mining companies and regulators to change the size and shape of waste dumps, and to seed with species found in the adjacent undisturbed areas to hasten the colonization of vertebrate species on to waste dumps and the creation of functional ecosystems.

Key words: Rehabilitation, Reptiles, Mammals, Mining, Succession.

INTRODUCTION

WHEN disturbed mine sites are rehabilitated, the creation of a near-natural, self-sustaining, functional ecosystem may be an objective (ICMM 2006, section 4.3). Most often top soil is spread over the waste dump, it is seeded and then ripped to minimize erosion and cause water to pool to facilitate seed germination. Invertebrates and vertebrates are expected to colonize the rehabilitated areas from the adjacent ecosystems when appropriate niches become available.

The patterns and processes of succession after fire and in rehabilitated areas have frequently been examined. The rate of colonisation for various taxa has often been used as an index of rehabilitation progress. For example, in Australia invertebrates, and in particular ants, have been used to assess rehabilitation progress (Andersen 1992, 1993; Majer 1983, 1985, 1989; Majer and Beeston 1996; Majer and Nichols 1998; Andersen et al. 2003), as have reptiles and mammals (Fox and Fox 1978, 1984; Fox 1990, 1992, 1996, 1997; Twigg and Fox 1991; Thompson 2004).

Twigg et al. (1989), Wilson and Friend (1999) and Monamy and Fox (2000) suggested that for small mammals, particularly after wildfires, colonization into disturbed areas is closely related to successional changes in the vegetation, with both structure and floristic pattern being important. Fox and his colleagues (Fox and Fox 1978; Twigg et al. 1989; Fox 1990, 1996, 1997) suggested that most small mammals will colonize

a rehabilitated area in the first 10–20 years, presuming suitable habitats are available. Although there is a paucity of long-term chronosequence data for reptile movement into rehabilitated areas, the available data suggest that reptiles are slower to colonize rehabilitated areas than mammals (Nichols and Bamford 1985; Walker et al. 1986; Twigg and Fox 1991; Halliger 1993; Taylor and Fox 2001; Thompson and Thompson 2005). More recently, Taylor and Fox (2001) showed a clear sequence of changes in the most abundant lizard species in a rehabilitated mine site from 4 to 20 years after mining.

This study describes those mammal, reptile and frog species that appear early in rehabilitated mined sites in the Goldfields of Western Australia and compares them with those species that are in low abundance or not present in rehabilitated areas, and are probably late colonizers.

METHODS

Study site

We examined the small vertebrate trappable faunal assemblages on five rehabilitated mine site waste dumps and the adjacent undisturbed areas in the gold mining region of Ora Banda (30°27'S, 121°4'E; approximately 50 km north of Kalgoorlie, Western Australia; Fig. 1). Ora Banda lies on Archaen granites that underlie lateritic

gravel soils. The vegetation was heterogenous, ranging from Eucalypt-Casuarina-Mulga woodlands interspersed with *Acacia*, to sparsely distributed spinifex (*Triodia* spp.) and shrubs (*Acacia* spp.) to dense shrubs (*Acacia* spp., *Atriplex* spp., *Allocasuarina* spp.). Vegetation on the rehabilitated waste dumps varied appreciably and was not the same as in the adjacent undisturbed areas, although mine site staff had attempted when seeding the waste dumps to use a seed mix that would produce a vegetation community similar to that in the general vicinity. Because chenopod seed is cheap and relatively easy to germinate, it tends to dominate the vegetation on most waste dumps in the region. Vegetation descriptions for each site for 2000/01 are available at http://www.business.ecu.edu.au/schools/mtl/staff/gthompson.htm.

When we commenced this project in June 2000, rehabilitation had been in place at Wendy Gully waste dump for three years, at Palace waste dump for four years, at Rose waste dump for seven years, and at Gimlet waste dump for eight years. Rehabilitation at Golden Arrow waste dump was done in two-stages: on the top it was five years old and on the sides it was nine years old. We assumed the primary source of colonizing vertebrate species onto waste dumps was from the adjacent undisturbed areas. Reptiles, frogs and mammals were present on all waste dumps, but not all the species in the adjacent undisturbed areas were present. We described all five waste dumps in an early stage of succession.

Data collection strategies

We used a trapping programme to sample mammal, reptile and frog assemblages on rehabilitated waste dumps and in the adjacent undisturbed areas on 12 occasions. During the first two years, four rehabilitated mine site waste dumps (Gimlet, Palace, Rose and Wendy Gully) and the adjacent undisturbed areas where surveyed on ten occasions (June 2000, September 2000, December 2000, January 2001, April 2001, June 2001, September 2001, December 2001, January 2002 and April 2002). They were again surveyed during January 2003 and 2004. Golden Arrow was included in the survey programme in June 2001, and was included in all subsequent surveys.

Pit-traps only were used during the first eleven surveys. Each trapping line consisted of three alternating 20 L PVC buckets and 150 mm PVC pipes (600 mm deep) dug into the ground along 30 m fly-wire drift fences that were approximately 250 mm high. In undisturbed areas adjacent to each waste dump we installed eight lines of six pit-traps. For rehabilitated areas, there were six lines of six pit-traps on the slope of the dump and another six lines of six pit-traps on the top of the dump. During the last survey, three pairs of funnel-traps were evenly spaced along each drift fence between pit-traps (Fig. 1). Funnel-traps were made of netting with ends 170 × 170 mm and a length of 750 mm. There was a funnel in each end with an opening of about 50 mm diameter. A pair of funnel-traps was

Layout of pit-traps in undisturbed areas
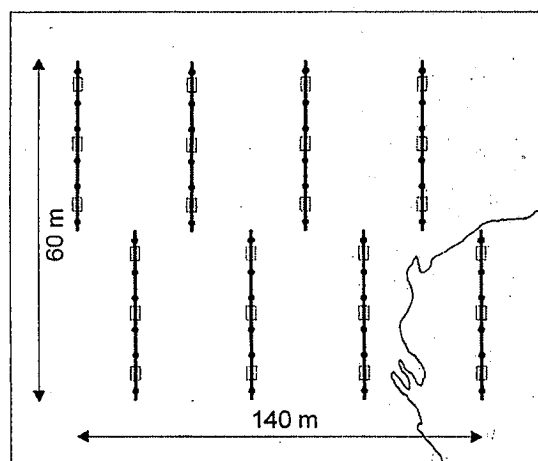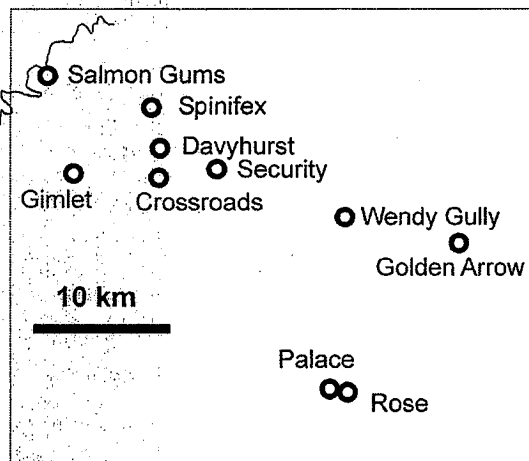
Study sites around Ora Banda

Fig. 1. Study site and pit-trap layout.

placed next to each other on either side of the drift fence (Fig. 1), and because a pair had about the same propensity to catch animals moving along the drift fence as a pit-trap that was positioned directly under the drift fence, a pair was counted as a single trapping unit. For the first eleven surveys, each pit-trap was open for seven days and cleared daily. For the survey in January 2004, each trap was left open for 14 days and cleared daily to provide a total of 54 516 trap-nights of data. Most reptiles and mammals were released near their point of capture. A few individuals were lodged with the Western Australian Museum as voucher specimens.

Data Analysis

The analysis compares both species richness and relative abundance of reptiles, frogs and mammals on a waste dump with that in the adjacent undisturbed area. Because the trapping effort on each waste dump was different to that in the adjacent undisturbed area, all capture rates were converted to captures per 1 000 trap-nights.

Data analysis addressed two issues; a) relative abundance and diversity of species on a waste dump, and b) a comparison of the relative abundance of species on waste dumps with that in the adjacent undisturbed areas. If the relative abundance of a species was less than one capture per 1 000 trap-nights in the undisturbed area and it was not found on the adjacent waste dump or vice versa, it was categorized as "low" (= low abundance). We were cautious about inferring much from these data about a species' colonizing ability because variations in catch rates could be due to sampling error. Species that had successfully colonized waste dumps were categorized into three groups: a) when 1–2 individuals per 1 000 trap-nights were captured; b) when >2–5 individuals per 1 000 trap-nights were captured, and c) when >5 individuals per 1 000 trap-nights were captured.

In the comparative analysis we endeavoured to place all species into one of three groups. If a species was relatively abundant in the undisturbed area and not found on the adjacent waste dump or was only found in low numbers (ratio of catches in undisturbed : waste dump >2), then we categorized this species as "slow" (= slow colonizer). If the converse was the case, that is, a species was in relatively low abundance in the undisturbed area, but in relatively high abundance on the adjacent waste dump (ratio of catches in undisturbed: waste dump <0.5), then we interpreted this to mean the species was an earlier colonizer and had flourished, and we categorized this species as "fast" (= fast colonizer). Our third category contained those species whose relative abundance was similar in the undisturbed area and on the waste dump (ratio of catches in undisturbed: waste dump between 2 and 0.5), and we called this category "similar" (= relative abundances were similar).

RESULTS

We caught 3 239 reptiles, 2 121 mammals and 517 frogs on all sites during the 12 surveys. Included were six species of Agamidae, eight species of Elapidae, 10 species of Gekkonidae, four species of Pygopodidae, three species of Varanidae, 17 species of Scincidae, three species of Typhlopidae, two species of frogs and 11 species of mammals (Table 1). We were unable to confidently differentiate *Ningaui ridei* and *N. yvonneae* in the field, so for the purposes of this analysis they were grouped. Of these, eight species of reptiles, one species of frog and six species of mammals had catch rates on a least one waste dump of higher than one per 1 000 trap nights.

Three species of reptiles (*Diplodactylus graneriensis, Heteronotia binoei, Underwoodisaurus milii*), one species of frog (*Pseudophryne occidentalis*) and five species of mammals (*Cercartetus concinnus, Mus musculus, Pseudomys bolami, Sminthopsis crassicaudata* and *Sminthopsis dolichura*) were caught on waste dumps at a rate >5 per 1 000 trap-nights. Six species of reptiles and one species of mammal had a catch rate on waste dumps >2–5 individuals per 1 000 trap-nights (Table 1).

Three species of reptiles (*Pogona minor, H. binoei, U. milii*), one species of frog (*P. occidentalis*) and three species of mammals (*M. musculus, P. bolami, S. crassicaudata*) had capture rates at least 2× more on waste dumps than in adjacent undisturbed areas, and so were categorized as fast colonizers. All agamids were classified as slow colonizers, except *P. minor* (which had a relatively high capture rate on waste dumps) and *Ctenophorus reticulatus* (which was caught in similar numbers on the Rose waste dump and in the adjacent undisturbed area). The number of elapids caught was generally too low to make a judgement about their colonizing capacity. However, there were adequate data for the elapid *Parasuta monachus*, which was classified as slow to colonize waste dumps. Adequate data were available for two species of blind snakes (*Ramphotyphlops australis, R. hamatus*), which were both classified as slow to colonize rehabilitated waste dumps.

The geckos *D. graneriensis, H. binoei, Strophurus assimilis* and *U. milii* were classified as either similar (in abundance) or fast colonizers of waste dumps. All other geckos where classified as slow colonizers except for *Oedura reticulata*, for which we had inadequate data. Except for *Delma australis*, which we only found in the undisturbed areas, our data for pypopods were generally inadequate to draw conclusions about their colonizing ability.

Table 1. Reptile and mammal species caught on five waste dumps and the adjacent undisturbed areas during 12 survey periods.

Species	Gimlet dump	Gimlet undist	Gimlet ratio	Golden Arrow dump	Golden Arrow undist	Golden Arrow ratio	Palace dump	Palace undist	Palace ratio	Rose dump	Rose undist	Rose ratio	Wendy Gully dump	Wendy Gully undist	Wendy Gully ratio	Presence on waste dumps: low >1.0	1-2	2-5	5+	Comparison: slow <2.0	similar 2-0.5	fast >0
AGAMIDAE																						
Ctenophorus cristatus		0.21	2.13		4.42			2.13		0.71	0.21	2.98	0.283	0.638					*	*		
Ctenophorus reticulatus	0.14	2.13			0.43			2.13		1.70	2.98		0.283	14.881				*		*		
Ctenophorus scutulatus														3.614						*		
Moloch horridus														4.677						*		
Pogona minor	1.417	0.425	0.300	0.220	3.307					2.551	0.425		1.559	0.213					*			*
Tympanocryptis cephala	0.425	1.488	8.501	3.307	4.762		3.543	0.213		0.142									*			
ELAPIDAE																						
Brachyurophis semifasciata		1.276			0.340			0.425												*		
Demansia psammophis	0.638	0.638					0.142	0.425		0.283	0.425		0.425						*			
Parasuta monachus	0.850	0.850		0.220			0.850	0.213		0.638	1.063		1.063						*			
Pseudechis australis	0.142			1.020	0.340		2.338	2.338		0.142									*			
Pseudonaja modesta				0.340	0.340		0.142			0.142			0.213							*		
Pseudonaja nuchalis	0.142										0.425									*		?
Simoselaps bertholdii		0.425		0.220																?		
Suta fasciata		0.638						0.425			0.213		0.142							?		
GEKKONIDAE																						
Diplodactylus granariensis	3.401	14.243		0.661	3.741		0.283	11.054		7.937	12.330		7.795	15.944				*		*		
Diplodactylus maini	0.142	11.480			0.680		0.283	7.228			13.180								*			?
Diplodactylus pulcher	0.142	3.827		0.441	23.129		0.567	16.794		0.567	19.770		7.866					*		*		
Gehyra purpurascens		0.213			0.340			1.488			1.276									*		
Gehyra variegata	2.693	6.803		7.483			0.283	8.929		1.417	6.165		0.283	2.338					*		*	
Heteronota binoei	3.118	0.638		12.346	0.680		3.543	4.039		1.701	0.850		3.118	0.638					*	*		
Oedura reticulata																						
Rhynchoedura ornata	0.709	1.063			6.803		4.252	19.345					0.850						*		*	
Strophurus assimilis		6.122		0.142	0.213					3.260	23.810							*		*	
Underwoodisaurus milii	35.006	2.338		28.439	6.803		7.511	2.338		14.739	1.488		5.385	4.039				*		*		
PYGOPODIDAE																						
Delma australis	0.425				0.340			1.701		0.142	0.213			1.063					*			
Delma butleri														0.425						*		
Lialis burtonis		0.213												0.425						*		
Pygopus lepidopodus														0.213						*		
VARANIDAE																						
Varanus caudolineatus	2.338									0.425	0.213		1.276	1+				*				*
Varanus gouldii	1.276		0.661	1.020			0.638			0.142	0.850		0.142							?		?
Varanus tristis										0.142										?		
SCINCIDAE																						
Cryptoblepharus plagiocephalus	2.126	2+			0.340		0.142	1.063			1.488		0.142	18.282			*			*		
Ctenotus alleni					0.213			0.213					0.142	0.213						*		
Ctenotus schomburgkii	1.913		0.441	8.503			0.850			0.425	0.425		0.425	4.039				*		*		
Ctenotus uber				1.361			0.425			0.142	0.638		0.142	4.677						*		
Cyclodomorphus melanops	0.283	11.054																				?
Egernia depressa								1.701			1.063			0.213						*		
Egernia formosa											1.063			0.213						*		
Egernia inornata											10.629			0.213						*		
Egernia striata	0.283	0.425			0.340									0.213						*		
Eremiascincus richardsonii	0.142	0.850																				*
Hemiergis initialis		0.638			1.020		0.142	1.276		0.283	1.063			0.425					*	*		
Lerista muelleri		0.638			5.782			1.063		1.063	1.063		0.425	4.089				*		*		
Lerista picturata	0.283	3.614			2.041		1.134	4.889		1.063	3.827		0.213	0.213				*		*		
Menetia greyii								1.063		3.260	3.614							*		*		
Morethia butleri	0.283	0.213																		*		
Tiliqua occipitalis		0.213											0.213							*		
Tiliqua rugosa	0.213		0.441		0.340			0.425			0.213									?		?

Table 1. — continued

Species	Gimlet dump	Gimlet undist	Gimlet ratio	Golden Arrow dump	Golden Arrow undist	GA ratio	Palace dump	Palace undist	Palace ratio	Rose dump	Rose undist	Rose ratio	Wendy Gully dump	Wendy Gully undist	WG ratio	Presence low >1.0	1–2	2–5	5+	Comparison slow <2.0	similar 2–0.5	fast >0.5
TYPHLOPIDAE																						
Ramphotyphlops australis	0.142	2.551					0.283	1.276		0.142	0.213		0.142	0.638		*				*		
Ramphotyphlops bituberculatus				0.882	5.102		0.283	1.063		0.283	1.276			1.913		*				*		
Ramphotyphlops hamatus	0.142	3.614																				*
AMPHIBIANS																						
Neobatrachus sutor	1.417	5.527		0.220	3.741		0.992	5.102		0.850	1.488		0.142			*				*		
Pseudophryne occidentalis	36.990	15.094					0.425	18.495			0.425									*	*	
MAMMALS																						
Antechinomys laniger										0.142			0.142	2.976		*				*		
Cercartetus concinnus	6.661	12.968		3.086	10.884		2.126	4.252		3.827	4.677		1.701	2.126							?	
Mus musculus	25.794	5.315		11.905	0.680		12.897	5.102		12.188	4.677		35.714	4.039				*	*			*
Ningaui spp. (2 species)				0.661	6.463						0.850		0.283			*				*	?	
Notomys mitchelli	0.142												0.142			*					? ?	
Pseudomys albocinereus				14.330	0.680		0.425	2.338		5.952	4.677			0.638					*	*	*	
Pseudomys bolami	3.543	2.338		2.866	1.020			0.638		0.425	2.338		0.425	0.850				*		*	*	
Pseudomys hermannsburgensis	0.992	1.063		7.055	4.762		15.731	2.338		27.778	5.527		30.329	4.252					*			*
Sminthopsis crassicaudata	5.102	0.425		6.614	6.463		0.850	7.228		0.567	5.102		1.134	5.952					*		*	
Sminthopsis dolichura	0.850	0.850																		*	*	
SUMMARY																						
# of reptiles	343	380		230	274		138	375		263	505		165	566								
# of amphibians	271	97		1	11		10	111		6	9		1	0								
# of mammals	304	108		211	91		226	103		356	131		493	98								
# of reptile species	17	33		14	26		17	29		22	30		16	34								
# of amphibian species	2	2		1	1		2	2		1	2		1	0								
# of mammal species	7	6		7	7		5	6		6	7		8	7								

Units are catches per 1 000 trap-nights.

Varanids were generally caught in low numbers on and off waste dumps. We classified *Varanus gouldii* and *V. caudolineatus* as slow colonizers of rehabilitated waste dumps. Of the skinks for which we had adequate data, all were classified as slow to colonize rehabilitated waste dumps.

DISCUSSION

The topography, soils and vegetation on all five waste dumps examined were different to the adjacent undisturbed areas. This is the situation for almost all rehabilitated waste dumps in the Goldfields of Western Australia. Waste dumps in the early stages of rehabilitation often have their vegetation more sparsely distributed than in the adjacent undisturbed areas. The archaen granites that underlie the lateritic gravel typical of the undisturbed areas are generally well-weathered and slightly undulating. In contrast, waste dumps are huge structures 50 to 80 m high that dominate the landscape, with sides that often approach the angle of repose. The surface and sides of waste dumps are often eroded with deep gullies, and large cracks are evident in the surface as a result of soil washing down among the underlying substrate. In the early stages of rehabilitation a limited range of chenopod species often dominate the vegetation, whereas the adjacent undisturbed areas can be a sparse woodland containing a diverse range of perennials, typically species of *Allocasuarina*, *Acacia* and *Eucalyptus* over an understorey of species of *Atriplex*, *Maireana*, *Senna* and *Acacia*.

It is likely that the propensity for a small vertebrate to get caught in a pit or funnel-trap is positively related to the size of its activity area and the time it spends foraging. The habitat differences described above suggest that resources are scarcer on waste dumps than in the adjacent undisturbed areas (Thompson 2004). It is possible, therefore, that small vertebrates are active for longer and forage over larger areas on waste dumps than in the adjacent undisturbed areas, thereby increasing the probability of capture. Comparisons between catch rates on waste dumps and the adjacent undisturbed areas should therefore be interpreted with caution. However, we remain confident that the major trends described here are real, as we have adopted a conservative approach in our assessment.

Mammals

Overall, mammals that were relatively abundant in the adjacent undisturbed areas were also present in reasonable numbers on waste dumps. Twigg et al. (1989) reported for a rehabilitated sand mining area in New South Wales that *M. musculus* was the first mammal to return, followed by *Pseudomys novaehollandiae* and then *Sminthopsis murina*. Although we have no chronosequence

data on arrival order, our data also indicate that *Mus*, *Pseudomys* and *Sminthopsis* spp. are all early colonizers.

Mus musculus and *S. crassicaudata* flourish in disturbed areas whether they are well vegetated or not, and may have increased in abundance on waste dumps in the absence of competition or because of low predation pressures. In contrast, *S. dolichura* was more abundant in three of the undisturbed areas than in the adjacent waste dumps, and in similar population densities on the waste dump and undisturbed areas at two waste dumps. *Pseudomys hermannsburgensis* and *P. bolami* are ecologically similar and sympatric at all our undisturbed sites. *Pseudomys bolami* was found on all waste dumps and often in greater abundance than in the adjacent undisturbed areas, whereas *P. hermannsburgensis* was only found on three waste dumps. We conclude that the preferred microhabitats for *P. hermannsburgensis* and *P. bolami* differ in a way that we do not appreciate, accounting for the difference in the two species' propensity to colonize waste dumps.

Capture rates for *C. concinnus* varied appreciably among surveys, but our data indicated that it will colonize waste dumps that have a dense cover of vegetation during the early stages of rehabilitation. *Ningaui* spp were only caught in low numbers on two of the waste dumps, and are probably slow colonizers, due to a lack of appropriate habitat or prey on waste dumps, or they have low dispersal capabilities.

Overall, our data suggest that if a mammal species can survive in habitats that are sparsely vegetated, has a generalist diet and perhaps retreats to holes in the ground (e.g., *M. musculus*, *S. crassicauda*), then it is able to flourish on waste dumps in the Goldfields of Western Australia during the early development stages.

Herpetofauna

Neobatrachus sutor was only trapped immediately after rain, which influenced their catch rate (Thompson *et al*. 2003), whereas *Pseudophryne occidentalis* was caught many days after it had rained. Both species were caught on waste dumps and *P. occidentalis* was present in large numbers on one of the waste dumps and categorized as fast.

Medium and large snakes were seldom caught in pit-traps, and it was only when we used funnel-traps during the last survey that we caught the larger snakes. *Parasuta monachus* was the only elapid caught often enough to indicate the extent to which it utilizes waste dumps. It was caught in higher numbers in the undisturbed areas, and was therefore a slow colonizer. Two blind snakes for which we had sufficient data occurred in low numbers on rehabilitated waste

dumps indicating that they are slow colonizers. *Pogona minor* was one of the first reptiles on rehabilitated waste dumps and flourished in this habitat probably because of its preparedness to forage widely in open spaces and its omnivorous diet (Thompson and Thompson 2003).

Underwoodisaurus milii and *H. binoei* were consistently caught in large numbers on waste dumps and in most circumstances in greater numbers than in the adjacent undisturbed areas, indicating that they will flourish in the early stages of rehabilitation. *Diplodactylus graneriensis* and *Strophurus assimilis* were also present in large numbers on a couple of waste dumps, and seemed to require a good cover of chenopods to be present. *Gehyra variegata* was caught in reasonable numbers on two waste dumps and it was not evident to us why it had colonized these waste dumps and not others. *Diplodactylus maini*, *D. pulcher* and *Rhynchoedura ornata* were caught in large numbers in some of the undisturbed areas, but were never caught in high numbers on waste dumps. It is highly likely that there were insufficient termites to sustain the termite eating specialists *D. pulcher* and *R. ornata* on waste dumps and a possible lack of spider burrows on waste dumps might be the reason why *D. maini* was in low abundance. The number of pygopods caught was generally too low to infer much about their colonizing ability, but the preliminary data suggest that they are slow colonizers of waste dumps.

Although we caught more species of skinks than any other reptile taxa, they were generally caught in low numbers on waste dumps. *Menetia greyii* was the obvious exception, being caught in reasonable numbers on Palace and Rose. It is difficult to understand why this skink was present on some waste dumps when other skinks were not, because like a number of other skinks (e.g., *M. butleri*, *C. atlas*, *C. uber*) it is a terrestrial, active-foraging, diurnal invertivore. The fossorial and nocturnal skinks (*Eremiascincus richardsonii*, *Hemiergis initialis*, *Lerista muelleri* and *Lerista picturata*) were seldom caught on waste dumps, although *L. picturata* was relatively abundant in five undisturbed habitats and *L. muelleri* in three undisturbed habitats. The loose surface sand that is characteristic of the habitat for many of these fossorial species is often absent on waste dumps, although there is leaf-litter in which they could hide and forage. The two arboreal skinks, *Egernia depressa* and *E. formosa*, were generally not found on waste dumps because of a lack of suitable habitat (e.g., large trees with hollows). The mostly crepuscular *E. inornata* was only caught in the undisturbed areas adjacent to Rose and Palace waste dumps where it lives in colonies. Species that live in colonies seldom disperse widely (Gardner *et al*. 2001) and are therefore likely to be slow colonizers of waste dumps.

Overall pattern

The primary requirements for early colonizers on rehabilitated waste dumps would appear to be: good dispersal capabilities, tolerance of open spaces and unvegetated areas, and a non-specialist diet. Almost nothing is known of the dispersal ability for most of the reptile species caught in the Ora Banda area (however, see Thompson 1992, 1993, 1994, 1995; Pianka *et al.* 1998; Thompson *et al.* 1999). Body size has a very obvious effect on activity areas (Thompson 1999), with the larger reptiles foraging over much larger areas and are therefore more likely to incorporate waste dumps in their activity areas. Almost nothing is known of the spatial movement for many of the small skinks and Shine and his co-workers have documented movement patterns for some species of elapids (e.g., Whitaker and Shine 2003), however, there are few data for those snakes caught around Ora Banda. Like large varanids, it would appear the activity areas for large snakes could extend onto waste dumps, although much of their foraging and retreats could be in the adjacent undisturbed areas.

A high proportion of the smaller reptiles were either not caught on waste dumps or where caught in low numbers. A lack of suitable niches (e.g., sandy soil, hollow trees and logs) and low dispersal capabilities might be the primary factors contributing to this large number of late colonizers. In contrast, it appears that many of the small mammals have a capacity to move great distances when necessary. For example, Dickman *et al.* (1995) reported that *P. hermanns-burgensis* and *S. dolichura*, both of which were caught in all undisturbed areas and on most of the waste dumps, have a capacity to move many kilometres. It is therefore likely that many of the small mammals would have moved onto the waste dumps at some time, but may not have established because of unsuitable conditions. Other than *Ningaui* spp. all of the commonly caught small mammals were found on some rehabilitated waste dumps in reasonable numbers.

Underwoodisaurus milii, H. binoei, M. musculus and *S. crassicauda* are probably the first of the reptiles and mammals that move onto waste dumps because they can exploit a diverse range of developing niches. *Pogona minor* probably also should be included with this group, but its relative abundance on and off the waste dumps makes its classification less obvious. The consequence is that in the absence of competitors for the same resources these species can increase their relative abundance to levels greater than in the adjacent undisturbed areas. Habitat or dietary specialists with needs that are not provided for on waste dumps during the early stages of rehabilitation will generally be late colonizers. For example, species that retreat to tree hollows (e.g., *E. depressa, E. formosa*) are not early colonizers, due to the lack of suitable habitat. Termite eating specialist geckos (e.g., *D. pulcher, R. ornata*) are seldom caught on waste dumps due to a lack of suitable food. Two burrowing snakes, *B. semifasciata* and *S. bertholdi*, with specialist diets were generally not caught in rehabilitated waste dumps, probably because of a lack of sandy substrate and skinks. Many of the terrestrial skinks that depend on leaf litter for cover (and food) are unlikely to occur on rehabilitated waste dumps, as most dumps in early stages of rehabilitation have large patches of bare earth.

In contrast, species that forage in, under or around chenopod shrubs (e.g., *P. minor, S. assimilis, D. graneriensis*) and have a more general diet are more likely to be early colonizers of rehabilitated waste dumps, because mine site managers often use chenopod seed in their rehabilitation programmes.

Implications for rehabilitation planning on mine site waste dumps

A primary objective for the rehabilitation of mine-site waste dumps should be the creation of self-sustaining, near-natural, functional ecosystems. Vertebrate faunal assemblages on waste dumps will only be similar to those in the adjacent undisturbed areas if the soils and vegetation are similar, thereby providing a similar range of habitat niches. As environmental rehabilitation bonds are most often based on the size of the disturbance, mine-site managers (and government regulators) prefer to establish high, steep-sided waste dumps with a small footprint instead of lower waste dumps with more gently sloping sides. These high, steep-sided structures are not typical of the heavily weathered terrain in the Goldfields and are prone to gully erosions, exposing the underlying substrate which often does not support a diverse range of vegetation. In addition, surface soil brought onto waste dumps is often different in texture and chemical composition to that in the adjacent undisturbed area. Rehabilitation seed mixes seldom match that of the adjacent undisturbed areas, and differential seed viability, plant growth rates and unsuitable soils mean that the vegetation communities on waste dumps are seldom similar to those in the adjacent undisturbed areas. A small proportion of the reptile assemblage in the undisturbed areas relies on hollow trees for retreats or feeds almost exclusively on termites. Suitable habitat, such as a range of logs of varying sizes and ages, should be placed on waste dumps during the rehabilitation process to encourage these species. Under current conditions only species with very plastic or with generalized diets and habitat requirements are likely to colonize waste dumps during the early

stages of development. Even when conditions are ideal, low dispersal capabilities and other pressures likely mean that some species will take many years to establish on rehabilitated waste dumps.

To hasten the creation of self-sustaining, near-natural, functional ecosystems on rehabilitated waste dumps, barriers between waste dumps and the adjacent vegetation need to be removed facilitating easier movement between habitats. More gently sloping sides that retain the surface soil and vegetation will provide a better transition between undisturbed and rehabilitated areas. Environmental bonding systems will need to be adjusted to account for the more environmentally appropriate outcomes associated with the different designs for waste dumps. Rehabilitation seed mixes need to be more carefully selected to facilitate the creation of both short and long-term vegetation communities on waste dumps similar to those in the adjacent undisturbed areas. Seed for rehabilitation should be collected from the adjacent or nearby undisturbed areas. More attention should be paid to the soils that are used for capping of waste dumps, so that they will support plant communities similar to those nearby. Decaying vegetation and logs need to be scattered on waste dumps to provide a range of niches for species that prefer hollows and termites.

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