Mammals or reptiles, as surveyed by pit-traps, as bio-indicators of rehabilitation success for mine sites in the goldfields region of Western Australia?

GRAHAM G. THOMPSON[1] and SCOTT A. THOMPSON[1]

We compare the relative merits of using mammals and reptiles as bio-indicators of rehabilitation success for mine sites in the semi-arid goldfields region of Western Australia (WA). Based on 54 600 pit-trap days of data we found that both mammals and reptiles colonized rehabilitated areas that were between three and nine years old. The complete suite of mammals generally return in the early stages of the rehabilitation programme, whereas the movement of reptiles into a rehabilitated area is spread over a much longer period. More reptile species seem to have specific requirements that are provided in the latter stages of the rehabilitation process. Using criteria of relative abundance, species richness, habitat preference, activity area and period, diet and foraging strategies, reptiles were assessed as a better bio-indicator than mammals. On other criteria such as population fluctuations, colonizing capacity and sensitivity to environmental changes, differences between reptiles and mammals were not as clear but most favoured reptiles as the preferred bio-indicator. Overall, we judged reptiles to have more merit as bio-indicators of rehabilitation success than mammals in the Ora Banda area.

Key words: Bio-indicators, Reptiles, Mammals, Rehabilitation, Mining.

INTRODUCTION

THERE have been many attempts to use a variety of flora and fauna as proxies to measure or monitor the degradation of the environment or the re-establishment of functional ecosystems after a disturbance (Karr et al. 1986; Fox, B. J. 1996; Bradford et al. 1998; O'Connell et al. 1998; Read 1999a; Anderson and Burgin 2002). Numerous researchers have used invertebrates, in particular ants, as bio-indicators of mine site rehabilitation progress (Andersen 1993; Majer and Beeston 1996; Majer and Nichols 1998; Andersen et al. 2003). Majer (1983) and Andersen et al. (2004) suggested that ants are good indicators because they are extremely abundant, are relatively species rich at most sites, have many specialist species that occupy higher trophic levels, are easily sampled and identified, and are responsive to changing environments. However, Andersen et al. (2003) reported the taxonomy of northern Australian ants is poorly known, and Majer in his many articles on using ants as indicators was often unable to identify many of the species that had been caught (see Majer 1983/84, 1985; Majer and Nichols 1998). Andersen et al. (2003) in summarizing the significance of their recent research using ants as indicators suggested that they were the first to demonstrate convergence between the ant assemblage on a rehabilitated area and the adjacent undisturbed area, and even then they were only able to do this for one of eight sites examined. Problems with using invertebrates as bio-indicators for rehabilitation success are related to the difficulty of identifying specimens to species level, and the enormous seasonal and year-to-year variability in species abundances that are determined by environmental variables unrelated to rehabilitation progress (Majer and Nichols 1998). Furthermore, invertebrate numbers generally may not correlate with changes in the ecosystem (Hilty and Merenlender 2000), although there are conflicting views on this issue (see Andersen et al. 2004 and references therein). Birds have also been used as bio-indicators (O'Connell et al. 1998; Mac Nally et al. 2004), however, they may be too mobile and transient to be useful at the scale of most mine site rehabilitated areas. Small trappable mammals and/or reptiles have also been used as bio-indicators. Fox and colleagues (Fox 1979, 1990, 1996; Letnic and Fox 1997; Monamy and Fox 2000) have used small mammals to monitor progress in the restoration of disturbed areas. In recent years, reptiles have also been used to monitor rehabilitation progress in disturbed areas (e.g., mine sites; Nichols et al. 1985; Halliger 1993; Ireland et al. 1994; Read 1999a). Read (2002) argued that small reptiles may be useful bio-indicators of the impact of cattle grazing in chenopod shrublands in South Australia because they are easily sampled and identified, respond quickly to environmental change, are abundant, and are not subject to dramatic seasonal fluctuations in population size and composition to the same degree as arid zone mammal and bird communities.

The literature contains commentaries on the usefulness and criteria for selecting bio-indicator or evaluation taxa that can be used to assess degradation or recovery of ecosystems (see reviews by Landres *et al.* 1988; Hilty and Merenlender 2000; Whitehead *et al.* 2001).

The objective of this paper was to examine the relative merits of using the pit-trappable mammal and reptile assemblages as bio-indicators for monitoring rehabilitation progress on mine sites in the semi-arid goldfields region of WA. This was done by comparing a number of attributes of mammal and reptile assemblages that were sampled in pit-traps around Ora Banda, approximately 50 km north of Kalgoorlie in WA.

METHODS

Criteria for determining the usefulness of a bio-indicator assemblage

We combined the relevant criteria suggested by Majer (1983), Karr *et al.* (1986), Kelly and Harwell (1990) and Hilty and Merenlender (2000) with some of our own, to derive criteria for assessing the relative merits of mammals and reptiles as bio-indicators of rehabilitation success (see Table 1 for a list of criteria and descriptions). Criteria have been grouped as follows: information content, quality of information provided, usefulness of information to management and practicability, and have been labelled A to P. Each of these criteria were applied to the

Table 1. Criteria and the attributes used to assess the suitability of mammal and reptile assemblages as a bio-indicator of rehabilitation success.

Criteria	Preferred attributes and issues
INFORMATION CONTENT	
A Relative abundance	Catch rates need to be sufficiently high for a "reasonable" trapping effort to provide accurate estimates of species richness, diversity and relative density/abundance.
B Species richness	High species richness provides the opportunity for different species to fill a variety of niches.
C Habitat preference	Taxa that remain within the rehabilitated area indicate that the habitat is meeting their needs (e.g., shelter, food). Those species with a narrow range of habitat preferences are the better bio-indicators.
D Activity area	Large or shifting activity areas can imply taxa are accessing resources from outside the rehabilitated area.
E Activity period	Taxa partition the environment based on activity period (e.g., diurnal or nocturnal), and it is preferable for the indicator assemblage to include species that use the full spectrum of activity times.
F Predatory and foraging strategy	Taxa cover a range of predatory strategies (e.g., sit-and-wait, actively foraging or widely foraging), and it is preferable for the indicator assemblage to include species that occupy the full spectrum of predatory strategies.
G Diet and trophic level	Taxa to occupy a range of trophic levels (e.g., omnivores, invertebrate carnivores or vertebrate carnivores); including generalist and specialists feeders (e.g., monophagous or oligophagous), and covering all available specialist dietary niches.
INFORMATION QUALITY	
H Population fluctuation, reproductive rate, and signal-to-noise ratio	Taxa with a range of reproductive rates, enabling some species to respond rapidly to changing environmental conditions, but with low year-to-year population fluctuations as a response to environmental factors unrelated to rehabilitation progress (e.g., resource availability or weather). Response to irrelevant environmental variables to be low (e.g., weather, seasonal seed availability).
I Colonizing capacity	Ability of taxa to colonize an area when conditions are suitable.
J Succession processes and hierarchical suite of indicators	Primary and secondary succession processes understood; succession processes occurring over a sufficiently long period for monitoring to be correlated with rehabilitation progress. Presence/absence and abundance of various species within the assemblage respond to appropriate environmental and rehabilitation cues.
RELEVANCE TO MANAGEMENT	
K Sensitivity to appropriate environmental changes and response rates suitable for intended application	Taxa need to respond in an understood manner to environmental changes relevant to progression toward an appropriate functional ecosystem. Colonization/succession processes spaced over a period of years that reflects the rehabilitation time scale.
L Adaptive management potential	Presence/absence or high/low abundance of particular species can be interpreted in the context of what environment changes/management practices are necessary for corrective action.
PRACTICALITY	
M Taxonomic status	Ability to identify accurately species, if undescribed, then the ability to distinguish reliably one species from another in the field; availability of published identification keys.
N Trap-ability of taxa	Taxa easy to trap in the field with minimal training.
O Field costs	High cost effectiveness for monitoring an assemblage in the field (e.g., specimens captured per pit-trap night is high).
P Expertise to identify species	Easy to learn how to identify accurately taxa in the field.

mammal and reptile species sampled, and a judgement was made about the usefulness of these assemblages as bio-indicators. In our assessment we sometimes examined whether the selected criterion was useful before we compared the two assemblages as bio-indicators.
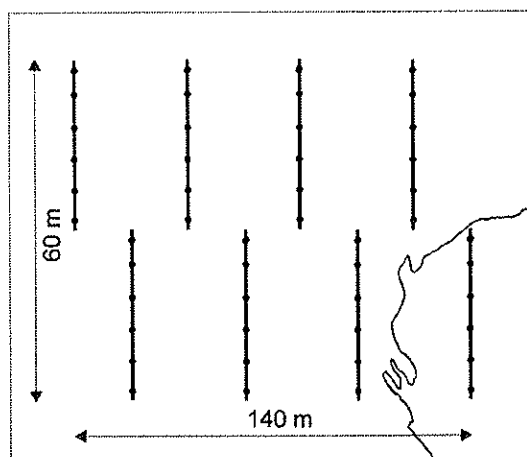
Study site

We sampled communities of mammals and reptiles over a 2 year period at five rehabilitated mine site waste dumps (Gimlet, Golden Arrow, Palace, Rose and Wendy Gully) and the adjacent undisturbed areas, plus another five undisturbed areas (Salmon Gums, Spinifex, Davyhurst, Security and Crossroads) in the gold mining region of Ora Banda (30°27'S, 121°4'E; approximately 50 km north of Kalgoorlie, WA; Fig. 1), as our primary source of information. Rehabilitation had been in place at Wendy Gully for 3 years, at Palace for 4 years, at Rose for 7 years, at Gimlet for 8 years, and at Golden Arrow there was a two-stage rehabilitation. Rehabilitation on the top of Golden Arrow waste dump was 5 years old and the sides were 9 years old. Waste dumps surveyed are adjacent to the undisturbed site that was surveyed, with the only separation being a two wheel track. The five undisturbed areas that were not adjacent to a waste dump were only included in the analysis of; a) the number of individual caught in undisturbed areas, and b) catch rates adjusted for variations in the trapping effort. When comparison was made between rehabilitated areas and undisturbed areas, only those undisturbed areas that were adjacent to rehabilitated areas were used in the analysis.

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.). The 10 undisturbed areas were located in different habitats based on major vegetation types identified for the area by Mattiske Consulting (1995).

Data collection strategies

Other than Golden Arrow, which was sampled on five occasions between spring 2001 and winter 2002, all other sites were sampled on 10 occasions between spring 2000 and winter 2002 (September, December, January, April and June) using alternating 20 L PVC buckets and 150 mm PVC pipes (600 mm deep) joined by 250 mm high × 30 m fly-wire drift fences (Fig. 1). In undisturbed areas there were eight rows of six pit-traps. For rehabilitated areas, there were six rows of six pit-traps on the slope of the dump (batters) and another six rows of six pit-traps on the top of the dump. During each field trip, each pit-trap was open for seven days and pit-traps were cleared daily. Each capture was sexed (where possible), weighed, measured and toe clipped. Most reptiles and mammals were identified before immediately being released near the point of capture. A few individuals were lodged with the WA Museum (WAM) as voucher specimens. Recaptures have not been used in the analysis of 54 600 pit-trap days of data.

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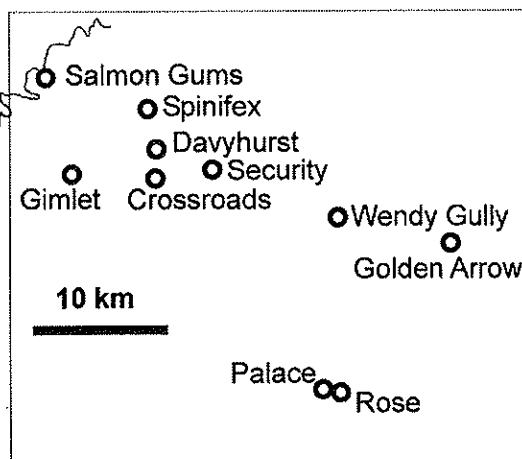
Study sites around Ora Banda

Fig. 1. Study sites in the vicinity of Ora Banda, with the insert showing pit-trap layout in undisturbed areas.

Data analyses

We examined the usefulness of the mammal and reptile assemblages as an indicator of rehabilitation success using the criteria in Table 1. We supplemented our data on species ecology with information mostly from Australian literature.

We used the diagnostic keys in Storr *et al.* (1983, 1990, 1999, 2002) to identify reptile species. If there was any doubt about a specimen's identification then we deposited a voucher specimen with WAM (criteria M and P). To identify mammals, we used the descriptive information contained in Strahan (2000) and Menkhorst and Knight (2001), and deposited a voucher specimen with WAM (criteria M and P) to verify our identification. Difference in abundance (taken as a measure of relative abundance; criterion A) of mammals and reptiles was determined by a repeated measures ANOVA [dependent variables; 1) taxa (mammals vs reptiles), 2) trap-type (buckets vs pipes), survey year (2, — repeated), season (September, December, January, April — repeated) and days (1–7, repeated)] for nine undisturbed sites (Golden Arrow was not included because of the different trapping effort). Difference in capture rates (criterion A) for mammals and reptiles was determined by analysing catch rates per 100 pit-trap days for each of the 10 survey periods across the 10 undisturbed areas and five rehabilitated areas using a repeated measures ANOVA [dependent variables; 1) taxa (mammals vs reptiles), 2) site type (undisturbed vs rehabilitated), survey year (2, — repeated) and season (September, December, January, April, June — repeated)]. Difference in the number of mammal and reptile species caught (criterion C) in rehabilitated and the adjacent undisturbed areas was determined using a repeated measures ANOVA [dependent variables; 1) taxa (mammals vs reptiles), 2) site type (undisturbed vs rehabilitated), survey year (2, — repeated) and season (September, December, January, April, June — repeated)]. Confidence limits were set at α = 0.05.

For criteria C, D, E, F and G all mammals and reptiles caught at Ora Banda were classified into one of three groups based on habitat preference (predominantly terrestrial = T, predominantly arboreal = A, predominantly fossorial = F); one of two groups based on activity period (predominantly nocturnal = N, predominantly diurnal = D); one of three groups based on predatory strategy (predominantly sit-and-wait = S, predominantly active forager = A, predominantly widely foraging = W); one of three trophic groups (predominately omnivore = O, predominately vertebrate carnivore = C, predominately invertebrate carnivore = I) and whether they were dietary specialists or generalists. An active

foraging predator was defined as a species that forages over a large search area looking for dispersed food sources (e.g., *Varanus gouldii*). A widely foraging predator was defined as a species that forages for a concentrated food source and then stays at that site for a period of time (e.g., *Moloch horridus* eating Formicidae). A sit-and-wait predator does not move around searching for prey but waits in ambush for prey to come past. A species was defined as a dietary specialist if greater than 85% of its diet came from one dietary category. Invertebrate dietary categories were; ants, beetles, cockroaches, crickets, centipedes, isopods, spiders, scorpions and termites. These particular groups were chosen because they were easily identifiable in reptile stomach contents and were consistent with how many authors reported reptile stomach content data (e.g., Pianka 1986). For example, *Moloch horridus* was defined as a dietary specialist as it only eats Formicidae (99%; Pianka 1986; Withers and Bradshaw 1995). If there were no published data on diet, habitat preference, predatory strategy, trophic group or activity period for particular species, then these species were assigned to a particular category based on personal observations and discussions with experienced ecologists and field biologists, including E. R. Pianka, P. C. Withers, R. How, B. Maryan, G. Harold and G. Shea. Differences between frequency in each of these groups (criteria C, D, E, F and G) for rehabilitated areas and the adjacent undisturbed areas were examined using Chi-squared tests calculated on the integer for the number of species or individuals caught per unit of trapping effort where appropriate, with α = 0.05.

Criteria H, I, J, K, L, N, O and P (Table 1) were assessed and discussed using reasoned arguments that are supported by the available data and the literature, as these criteria were not amenable to statistical analysis.

RESULTS AND DISCUSSION

Below we present results from our analysis and a discussion of the suitability of mammals and reptiles as bio-indicators for mine site rehabilitation areas using each of the criteria shown and elaborated on in Table 1. We caught 2 772 individual reptiles, 2 246 in undisturbed areas and 526 on rehabilitated areas, and 1 680 individual mammals, 718 in undisturbed areas and 962 on rehabilitated areas. We caught 51 species of reptile and 11 species of mammal in the vicinity of Ora Banda. We appreciate that the "age" (3–9 years) of rehabilitation, vegetation and soils types differ among rehabilitated sites, but we had to presume some uniformity among these sites when undertaking the analysis. This was necessary as there are very few rehabilitated waste dumps with similar soils and vegetation, and where the rehabilitation is of a similar age

and stage of development. This is an obvious limitation for this study.

Relative abundance (criterion A)

When comparing the number of individuals caught in nine undisturbed areas (Golden Arrow was not included), there were significant differences between mammals and reptiles, trap type (buckets vs pipes), year, and among seasons and days (Table 2). There were significant interactions between most of the effects (Table 2). More reptiles than mammals were caught in all survey periods other than June (winter; Fig. 2). For catch rates, there were significant differences between mammals and reptiles, rehabilitated and undisturbed areas, years and among seasons (Table 3). The abundance of reptiles, as measured by catch rates on rehabilitated areas, was generally less than that in the adjacent undisturbed areas for all sites and for the combined data set (Fig. 3). After accounting for the trapping effort difference between the five rehabilitated areas (approximately 71%) and the adjacent undisturbed sites, the number of individuals for each species of reptile caught was higher in the undisturbed areas than on rehabilitated areas. This was not the case for mammals, with two species of mammals (*Mus musculus* and *Sminthopsis crassicaudata*) being caught in greater numbers on the rehabilitated areas than in the undisturbed areas. The proportionally greater number of reptiles caught in undisturbed areas compared with rehabilitated areas suggest that reptiles would be

Table 2. Results from a repeated measures ANOVA on the total number of individuals caught [dependent variables; 1) taxa (mammals and reptiles), 2) trap-type (buckets vs pipes), survey year (2 x repeated), seasons (September, December, January, April — repeated), and days (1–7, repeated)] for undisturbed sites.

| Effect	df	F	P value
Taxa (1)	1, 32	134.20	0.000
Trap-type (2)	1, 32	27.03	0.000
Years (3)	1, 32	40.44	0.000
Seasons (4)	3, 96	36.49	0.000
Day (5)	6, 192	18.67	0.000
1*2	1, 32	36.81	0.000
1*3	1, 32	41.24	0.000
2*3	1, 32	8.35	0.007
1*4	3, 96	40.81	0.000
2*4	3, 96	3.39	0.021
3*4	3, 96	6.30	0.001
1*5	6, 192	8.70	0.000
2*5	6, 192	5.02	0.000
3*5	6, 192	5.79	0.000
4*5	18, 576	8.20	0.000
1*2*3	1, 32	10.01	0.003
1*2*4	3, 96	5.98	0.001
1*3*4	3, 96	3.87	0.012
2*3*4	3, 96	1.08	0.362
1*2*5	6, 192	4.66	0.000
1*3*5	6, 192	5.61	0.000
2*3*5	6, 192	2.16	0.048
1*4*5	18,576	8.48	0.000
2*4*5	18,576	2.29	0.002
3*4*5	18,576	6.09	0.000
1*2*3*4	3,96	1.11	0.347
1*2*3*5	6,192	3.56	0.002
1*2*4*5	18,576	1.86	0.017
1*3*4*5	18,576	4.42	0.000
2*3*4*5	18,576	1.38	0.136
1*2*3*4*5	18,576	1.69	0.037
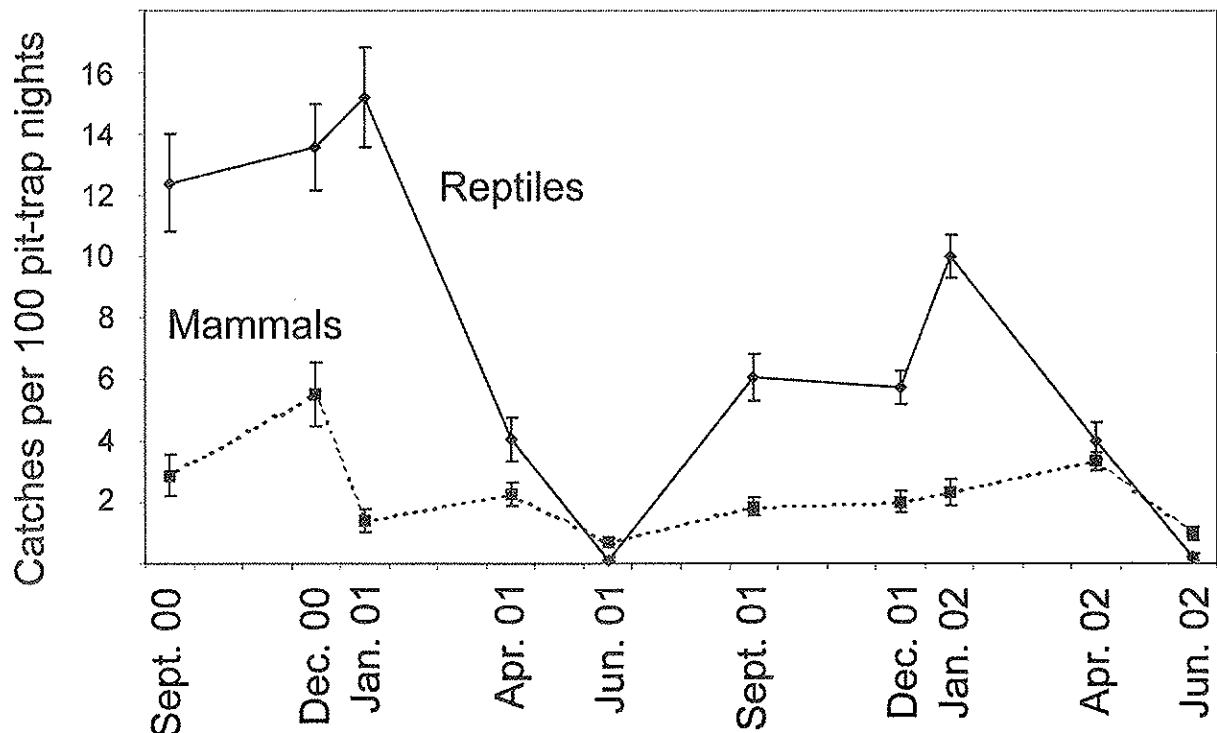
Fig. 2. Catch rates for reptiles and mammals for each of the 10 survey periods. Data presented are means and ± 1 se.

Table 3. Results of a repeated measures ANOVA for mammals and reptiles to determined differences in catch rates per 100 pit-trap days for each of the 10 survey periods across the 10 undisturbed areas and five rehabilitated waste dumps [dependent variables; 1) taxa (mammals and reptiles), 2) site type (undisturbed vs rehabilitated), 3) survey year (2 x repeated), and 4) season (September, December, January, April, June — repeated)].

Effect	df	F	P-value
Taxa (1)	1, 22	5.80	0.025
Site type (2)	1, 22	7.18	0.014
Year (3)	1, 22	35.29	0.000
Season (4)	4, 88	52.48	0.000
1*2	1, 22	50.84	0.000
1*3	1, 22	2.67	0.116
2*3	1, 22	1.63	0.215
1*4	4, 88	21.51	0.000
2*4	4, 88	8.21	0.000
3*4	4, 88	7.92	0.000
1*2*3	1, 22	14.85	0.001
1*2*4	4, 88	14.91	0.000
1*3*4	4, 88	1.73	0.151
2*3*4	4, 88	2.36	0.059
1*2*3*4	4, 88	2.07	0.091

a better bio-indicator of rehabilitation success than mammals using this criterion.

Species richness (criterion B)

High species richness increases the possibility of taxa occupying a diverse range of niches

(Pianka 1986), and thus having different species colonizing a rehabilitated area at different stages of the succession process, as appropriate niches become available.

At each undisturbed site we caught between 17–35 species of reptiles and 4–7 species of mammals (Table 4). On rehabilitated areas we caught between 9–16 species of reptiles and 5–8 species of mammals [three of the mammal species (Antechinomys laniger, Notomys mitchelli, Pseudomys albocinereus) were only caught once and in rehabilitated areas]. For the number of species caught there were significant differences between the mammals and reptiles, rehabilitated and adjacent undisturbed areas, and among seasons, but not years (Table 5). There was a significant interaction effect between taxa, site and season (Fig. 4). The mean number of mammal species caught in the undisturbed areas for any survey period was 2.75 (± se 0.143) compared with 3.08 (± se 0.234) on the rehabilitated areas. For reptiles, the mean number of species caught in undisturbed areas for all survey periods was 9.74 (± se 0.653) compared with 6.54 (± se 0.530) on the rehabilitated areas. Number of reptile species captured generally exceeded that for mammals during the warmer months, however, during the June surveys when reptiles were inactive, the number of reptile species was generally lower (Fig. 4).
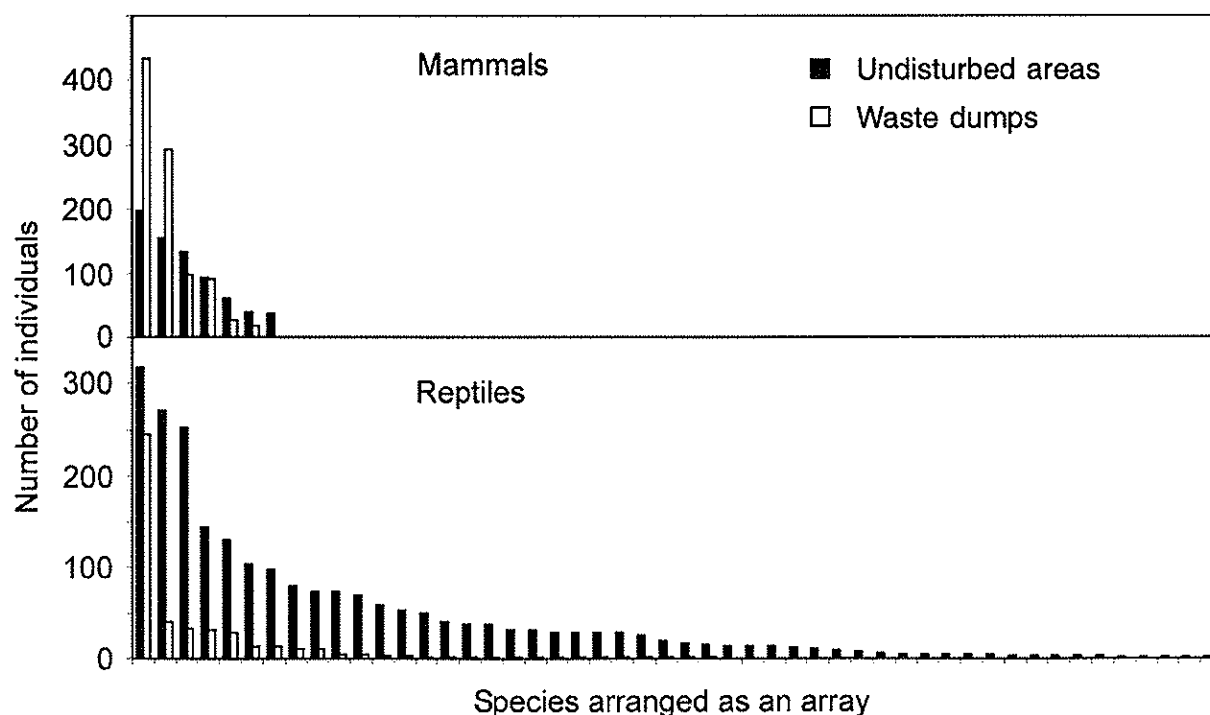

Fig. 3. The number of mammals and reptiles for each species caught across all undisturbed areas and rehabilitated areas arranged in an array (highest to lowest) to indicate difference in relative abundance between the two habitat types.

Table 4. Total number of species and small-trappable mammals recorded at each of the undisturbed sites over the 3 360 pit fall-trap days sampled, except for Golden Arrow, which was 1 680 pit-trap days plus the number of trap days taken to reach that total at each site.

	Reptiles		Mammals	
	Species richness	Trap nights	Species richness	Trap nights
Crossroads	22	3 264	6	1 968
Davyhurst	35	2 688	6	2 544
Gimlet	30	2 448	6	3 264
Palace	23	2 688	6	720
Rose	25	2 688	7	1 104
Salmon Gums	27	2 880	7	672
Security	22	2 448	4	3 168
Spinifex	32	2 784	6	384
Wendy Gully	25	2 448	7	1 056
Golden Arrow	17	1 104	7	960

Table 5. Results of a repeated measures ANOVA to determined difference in the number of species between; 1) taxa (mammals and reptiles), 2) site type (undisturbed vs rehabilitated), survey year (2 × repeated), and season (September, December, January, April, June — repeated)].

Effect	df	F	P-value
Taxa (1)	1, 26	84.39	0.000
Site type (2)	1, 26	9.99	0.004
Year (3)	1, 26	0.84	0.367
Season (4)	4, 104	50.94	0.000
1*2	1, 26	13.58	0.001
1*3	1, 26	0.04	0.837
2*3	1, 26	2.65	0.116
1*4	4, 104	32.22	0.000
2*4	4, 104	8.02	0.000
3*4	4, 104	4.22	0.003
1*2*3	1, 26	0.25	0.619
1*2*4	4, 104	6.53	0.000
1*3*4	4, 104	0.55	0.698
2*3*4	4, 104	1.21	0.312
1*2*3*4	4, 104	0.97	0.427

The higher number of reptile species compared with mammal species caught at each site provides greater scope for reptiles to occupy a diverse range of niches, and therefore the reptile assemblage would be a better bio-indicator of rehabilitation success than the mammal assemblage. This is discussed in more detail below. However, a higher pit-trapping effort was required to catch a representative of all of the reptile species known at each of the 10 undisturbed areas than was the case for mammals [mean traps-days to catch all reptiles $= 2\,544$ ($\pm$ se 1 78.0), for mammals $= 1\,584$ ($\pm$ se 338.6); t-test $= 2.51$, df $= 13.6$, $P < 0.05$; Table 4]. Therefore, although the reptile assemblage was a better bio-indicator using the criteria of relative abundance and species richness, the cost of the survey effort (criterion O) was higher for reptiles than for mammals if the same proportion of mammal and reptile species in the assemblage is to be trapped.
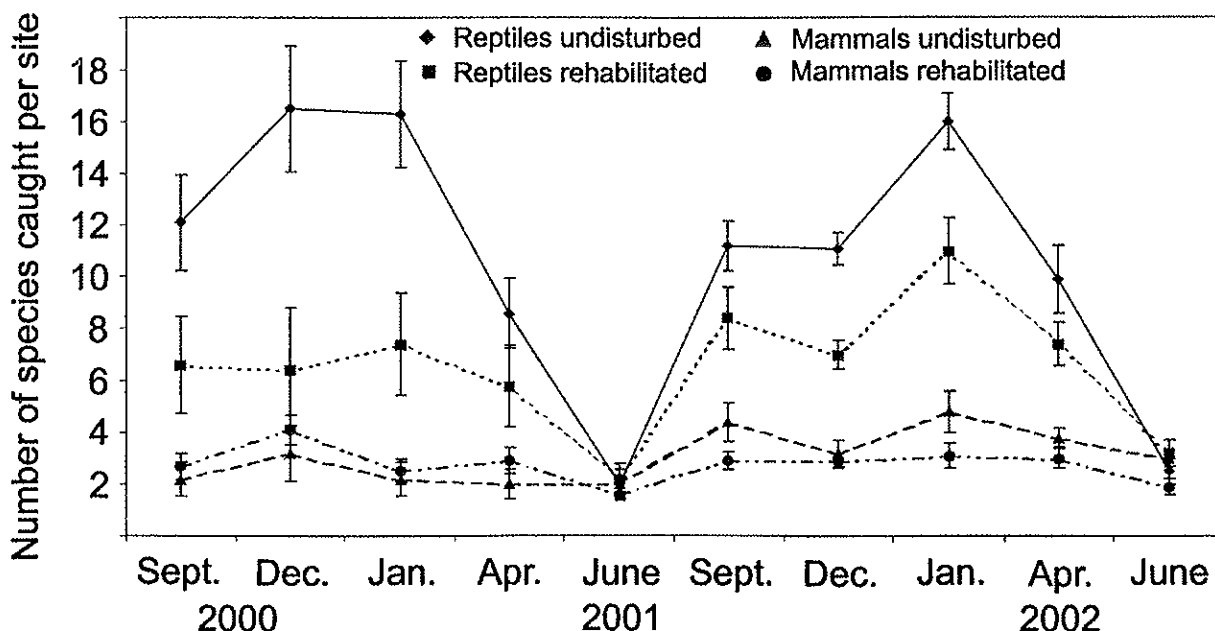

Fig. 4. Number of species caught, averaged across all rehabilitated sites and the adjacent undisturbed sites per season. Means with $\pm$ 1 se.

Habitat preference (criterion C)

Species partition the environment in various ways (e.g., activity period, predatory and foraging strategies, diet and trophic levels). Poorly vegetated rehabilitated areas are likely to have fewer vertebrates present than the adjacent undisturbed areas because of a lack of suitable habitat (Fox and Fox 1984; Nichols and Bamford 1985; Fox, B. J. 1990, 1996, 1997; Twigg and Fox 1991). If the majority of species in the assemblage under consideration are plastic in their habitat requirements, and overlap in their behaviour and niche requirements, then it is unlikely that the full complement of habitat niches available in undisturbed areas will be necessary to sustain the assemblage in the rehabilitated area. Therefore, assemblages with a range of species with narrow niche requirements (i.e., dietary and habitat specialists) are more useful as bio-indicators.

Rehabilitated areas often have few large trees, and mature large shrubs generally come after the grasses and sedges have been established. It might therefore be expected that species that prefer arboreal habitats (e.g., *Egernia depressa*), specifically mature trees and large shrubs, might colonize rehabilitated areas late in the succession process. All mammals caught in the adjacent undisturbed areas were caught on rehabilitated areas. Only one of the mammal species is predominantly arboreal, *Cercartetus concinnus*. One hundred and eleven of these were caught in the undisturbed area and 96 on the rehabilitated areas, although the trapping effort in the undisturbed areas was 71% of that in the rehabilitated areas. These data indicate there was appropriate habitat for these small marsupials on at least some of the rehabilitated areas, but their relative abundance was less in rehabilitated areas than the adjacent undisturbed areas.

There was a significant difference in the frequency of the total number of reptiles captured in the three habitat groups on the rehabilitated areas compared with the adjacent undisturbed area ($\chi^2_2 = 20.8$, $P < 0.05$). Of the 46 species of reptiles caught in the undisturbed areas, five of the eight arboreal, five of the nine fossorial, and 18 of the 29 terrestrial species were caught on the rehabilitated areas (Table 6). However, when we examined the number of individuals, there was a fifth as many arboreal, an eighth as many fossorial and two fifths as many terrestrial reptiles caught on rehabilitated areas as on the adjacent undisturbed areas. This was expected as the vegetation was generally less mature on the rehabilitated areas and the surface soil on the rehabilitated areas was not always typical of the weathered soils that were in the adjacent undisturbed areas. Both of these factors would have reduced the availability of suitable habitat for arboreal and fossorial species in the rehabilitated areas. Based on these data we concluded that the reptile assemblage was more useful as a bio-indicator than the mammal assemblage using this criterion.

Activity area (criterion D)

The better bio-indicator group would have more species with relatively small home ranges. Species that are transients or have large shifting home ranges (e.g., *Sminthopsis hirtipes*, *Pseudomys hermannsburgensis*, Dickman *et al.* 1995; Menkhorst and Knight 2001) possibly provide a relatively poor indication that environmental conditions on rehabilitated areas are suitable to sustain the species, as their activity area could include large

Table 6. Trophic levels, habitat preference, predatory strategy and activity period of all reptile and mammal species caught near Ora Banda.

Species	Trop	Hab	Pred	Act	Diet	Source
GECKOS						
Diplodactylus granariensis	I	T	S	N	G	Chapman and Dell 1985; Roberts 1998
Diplodactylus maini	I	T	A	N	G	Chapman and Dell 1985; How, R., unpubl. data; EX
Diplodactylus pulcher	I	T	W	N	S	Pianka 1969a, 1986; Pianka and Pianka 1976
Gehyra purpurascens	I	A	S	N	G	How, R., unpubl. data; EX
Gehyra variegata	O	A	S	N	G	Pianka 1969a; Pianka and Pianka 1976; Kitchener *et al.* 1988; Henle 1990a
Heteronotia binoei	I	T	W	N	G	Bustard 1968; Pianka 1969a; Pianka and Pianka 1976; Henle 1990b
Nephrurus laevissimus	I	T	S	N	G	Pianka 1969a, 1986; Pianka and Pianka 1976; Delean and Harvey 1981; How *et al.* 1990; EX
Oedura reticulata	I	A	A	N	G	Pianka and Pianka 1976; How and Kitchener 1983; Kitchener *et al.* 1988; How, R., unpub. data; EX
Rhynchoedura ornata	I	T	W	N	S	Pianka 1969a; Pianka and Pianka 1976; Roberts 1998
Strophurus assimilis	I	A	S	N	G	Roberts 1998
Underwoodisaurus milii	I	T	S	N	G	Chapman and Dell 1985; How *et al.* 1990; Read 1999b; EX
SKINKS						
Cryptoblepharus plagiocephalus	I	A	A	D	G	James *et al.* 1984; Pianka 1986; EX
Ctenotus atlas	I	T	A	D	G	Pianka 1986; EX
Ctenotus schomburgkii	I	T	W	D	G	Pianka 1986; Henle 1989; Read 1998; EX
Ctenotus uber	I	T	A	D	G	Read 1998; EX

Table 6 — *continued*

Species	Trop	Hab	Pred	Act	Diet	Source
SKINKS — continued						
Cyclodomorphus melanops elongatus	I	T	S	N	G	Cogger 1992; EX
Egernia depressa	I	A	S	D	G	Pianka 1969a, 1986; Storr *et al.* 1999; EX
Egernia formosa	I	A	S	D	G	Cogger 1992; EX
Egernia inornata	I	T	S	N	G	Pianka 1969a, 1986; Pianka and Giles 1982; Greer 1989; Henle 1989
Egernia striata	I	T	S	N	G	Pianka 1969a, 1986; Pianka and Giles 1982; Greer 1989; EX
Eremiascincus richardsonii	I	F	A	N	G	Pianka 1969a, 1986; Henle 1989; EX
Hemiergis initialis	I	F	A	N	G	EX
Lerista muelleri	I	F	A	N	G	Pianka 1986; EX
Lerista picturata	I	F	A	N	G	EX
Menetia greyii	I	T	A	D	G	Smyth and Smith 1974; Pianka 1986; Henle 1989
Morethia butleri	I	T	A	D	G	Pianka 1986; EX
Tiliqua occipitalis	O	T	A	D	G	Storr et al. 1999; EX
Tiliqua rugosa	O	T	A	D	G	Bamford 1980; Bull 1987; Henle 1989; Dubas and Bull 1991; Storr *et al.* 1999; EX
AGAMIDS						
Ctenophorus cristatus	I	T	S	D	G	Pianka 1971a; EX
Ctenophorus reticulatus	O	T	S	D	G	Pianka 1986; EX
Ctenophorus scutulatus	I	T	S	D	G	Chapman and Dell 1985; Pianka 1969a, 1971a, 1986; EX
Moloch horridus	I	T	W	D	S	Davey 1923; Thompson 2003; Withers and Bradshaw 1995; Withers and Dickman 1995; EX
Pogona minor	O	T	A	D	G	Chapman and Dell 1985; Pianka 1986; Thompson and Thompson 2003
Tympanocryptis cephala	I	T	S	D	G	EX
VARANIDS						
Varanus caudolineatus	I	A	A	D	G	Pianka 1969b, 1986; Thompson 1993; Thompson and King 1995
Varanus gouldii	I	T	A	D	G	Pianka 1970; Pianka 1986, 1994; Shine 1986; Thompson 1994, 1995 1996; EX
Varanus tristis	C	A	A	D	G	Pianka 1971b; Pianka 1986; 1994; Thompson *et al.* 1999; Thompson and Pianka 1999; EX
PYGOPODS						
Delma australis	I	T	A	D	G	Bustard 1970; Maryan 1984; Patchell and Shine 1986; EX
Delma butleri	I	T	A	D	G	Bustard 1970; Patchell and Shine 1986; EX
Delma fraseri	I	T	A	N	G	Pianka 1969a; Bustard 1970; Martin 1972; Maryan 1984; Chapman and Dell 1985; Patchell and Shine 1986
Lialis burtonis	C	T	S	D	S	Pianka 1969a; Bustard 1970; Martin 1972; Chapman and Dell 1985; Patchell and Shine 1986
Pygopus lepidopodus	I	T	A	D	S	Martin 1972; Smith and Chapman 1976; Fitzgerald 1983; Patchell and Shine 1986; EX
ELAPIDS						
Brachyurophis semifasciata	C	F	A	N	S	Webb 1983; How and Shine 1999; EX
Demansia psammophis	C	T	A	D	G	Orange 1991; Cogger 1992; Greer 1997; EX
Parasuta monachus	C	T	A	N	G	Shine 1988; Greer 1997; EX
Pseudonaja modesta	C	T	A	D	G	Gillam 1979; Greer 1997; EX
Simoselaps bertholdi	C	F	A	N	S	Swan 1983; Strahan *et al.* 1998; How and Shine 1999
Suta fasciata	C	T	A	N	G	Shine 1983; EX
SCOLECOPHIDIANS						
Ramphotyphlops australis	I	F	W	N	S	Webb and Shine 1993; Storr *et al.* 2002; EX
Ramphotyphlops bituberculatus	I	F	W	N	S	Webb and Shine 1993; Storr *et al.* 2002; EX
Ramphotyphlops hamatus	I	F	W	N	S	Webb and Shine 1993; Storr *et al.* 2002; EX
MAMMALS						
Antechinomys laniger	I	T	A	N	G	Strahan 2000; Menkhorst and Knight 2001
Cercartetus concinnus	O	A	A	N	G	Menkhorst and Knight 2001
Mus musculus	O	T	A	N	G	Bomford 1987; Moseby and Read 1998; Moro and Morris 2000; Miller and Webb 2001
Ningaui ridei	I	T	A	N	G	Kitchener 1995; McKenzie and Dickman 1995
Ningaui yvonneae	I	T	A	N	G	Kitchener 1995; McKenzie and Dickman 1995
Notomys mitchelli	O	T	A	N	G	Cockburn 1981; Watts 1995; Murray *et al.* 1999; Menkhorst and Knight 2001
Pseudomys albocinereus	O	T	A	N	G	Strahan 2000; Menkhorst and Knight 2001
Pseudomys bolami	O	T	A	N	G	Murray and Dickman 1994; Moseby and Read 1998
Pseudomys hermannsburgensis	O	T	A	N	G	Murray and Dickman 1994; Kotler, Dickman and Brown 1998
Sminthopsis crassicaudata	I	T	A	N	G	Morton 1995
Sminthopsis dolichura	I	T	A	N	G	EX

Trophic level (Trop): O = predominately omnivore, C = predominately vertebrate carnivore, I = predominately invertebrate carnivore; Habitat preference (Hab): T = predominantly terrestrial, A = predominantly arboreal, F = predominantly fossorial; Predatory strategy (Pred): S = predominantly sit-and-wait, A = predominantly active forager, W = predominantly widely foraging; Activity period (Act): N = predominantly nocturnal, D = predominantly diurnal; Dietary group (Diet): S = specialist, G = generalist. EX = personal communication with expert panel (R. How, B. Maryan, E. Pianka, G. Harold, G. Shea). Where multiple preferences are presented in the literature, we chose the most common or have taken advice from the expert panel.

sections of undisturbed habitat in which they find shelter or most of their prey. Little is known of the home range sizes for many of the small mammals we trapped, and activity areas are likely to be influenced by the availability of food, particularly for the rodents (Dickman et al. 1995; Wilson and Friend 1999). Dickman et al. (1995) reported significant movements for small mammal species in arid areas suggesting that some species have either very large, or shifting activity areas. For reptiles, details about activity area are known for a few species (Fergusson and Algar 1986; Thompson 1994; Bull and Freake 1999; Thompson et al. 1999; Thompson and Thompson 2003). For diurnal species such as *Ctenophorus reticulatus* and *Egernia depressa* that use a small number of visible perches for many days in succession, our observations indicate their activity areas are relatively small. Our observations are that most of the agamids that dig their own burrow have relatively small activity areas. The same is true for some gecko and skink species, as some individuals have been located in a small number of trees over many years (e.g., *Oedura reticulata*, How and Kitchener 1983). In contrast, larger snakes and varanids are likely to have shifting activity areas contained in larger home ranges (Green and King 1978; Thompson 1994; Thompson et al. 1999). From what we could glean from the literature and our observations, it appears as if the reptile assemblage has more species with small and defined activity areas compared to mammals, indicating that this assemblage was more useful as a bio-indicator than the mammal assemblage using this criterion.

Activity period (criterion E)

For activity period we divided taxa into two categories, "predominantly diurnal" and "predominantly nocturnal", although we acknowledge that species probably better fit a continuum more so than a dichotomy, and some species shift activity periods with environmental conditions. On the basis of the activity period criterion, reptiles are approximately evenly divided between two niches (51% diurnal and 49% nocturnal; Table 6), whereas all 11 mammal species are predominantly nocturnal. Therefore, mammals are not a useful discriminator based on activity period. Of the 22 nocturnal species of reptiles caught in the five undisturbed areas adjacent to rehabilitated areas, 14 were caught on the rehabilitated areas, and of the 24 diurnal species caught in the five undisturbed areas 14 were caught on the rehabilitated areas. There was no significant difference ($\chi^2_1 = 1.18$, $P = 0.28$) between the frequency of captures for nocturnal and diurnal reptiles on the rehabilitated areas compared with the adjacent undisturbed areas. These data suggest that

although this criterion had the potential to be useful to determine which of the two assemblages was the better bio-indicator, the lack of a difference between diurnal and nocturnal reptile species in the rate at which they return to rehabilitated areas meant it was of little value.

Predatory and foraging strategy (criterion F)

Although we categorized predatory strategies as "predominantly sit-and-wait", "predominantly actively foraging" and "predominantly widely foraging", we acknowledge that these foraging modes are somewhat artificial as there is likely to be both overlap among modes, and some species will adopt more than one mode (Perry 1999). We placed 31% of the reptile species caught at Ora Banda in the "predominantly sit-and-wait" mode, 53% in the "predominantly actively-foraging" mode, and 16% in the "predominantly widely foraging" mode (Table 6). We placed all 11 mammal species in the "actively foraging" mode, however, we were uncertain of this categorization for a number of the nocturnal mammal species because nothing is known of their foraging behaviour (e.g., *Cercartetus concinnus*, *Sminthopsis dolichura*).

The frequency of individual reptiles in each of the three predatory strategy groups differed significantly between the rehabilitated area and the adjacent undisturbed area ($\chi^2_2 = 2330$, $P < 0.01$). There was one ninth as many widely foraging reptiles, one sixth as many actively foraging reptiles and one half as many sit-and-wait reptiles caught on the rehabilitated areas as were caught in the adjacent undisturbed areas. Thirteen of the 23 actively foraging reptile species caught in the undisturbed areas were caught on the adjacent rehabilitated areas, 10 of 15 of the sit-and-wait, and five of the eight widely foraging reptile species caught in the undisturbed areas were caught on the rehabilitated areas. These data suggest that widely foraging species move into rehabilitated areas earlier than species with other foraging strategies, and that the reptile assemblage is a more useful bio-indicator using this criterion.

Diet and trophic level (criterion G)

The better bio-indicator assemblage should have a high proportion of specialist feeders, as these species indicate when a particular niche is available (e.g., termite specialists indicate the availability of termites and a suitable food source for termites), whereas generalists are much more adaptable and plastic in their requirements. The preferred bio-indicator assemblage should include species that feed in a variety of trophic levels (e.g., omnivorous, vertebrate carnivores or invertebrate carnivores). Higher order trophic species are useful bio-indicators of advanced

stages of rehabilitation progress, as they generally require a diverse and abundant range of other small vertebrates to persist in the area. However, many of these higher order trophic species (e.g., *Varanus gouldii*, *Pseudechis australis*) have large activity areas that can include both rehabilitated and undisturbed areas which can be problematic when interpreting their presence in rehabilitated areas.

Rodents were generally classified as omnivores and the marsupials, except for *C. concinnus*, predominantly invertebrate carnivores. *Ningaui* spp., *Sminthopsis crassicaudata* and *S. dolichura*, if given the opportunity, are also vertebrate carnivores. There was no significant difference ($\chi^2_1 = 0.24$, $P = 0.62$) in the frequency of invertebrate carnivorous and omnivorous mammals caught on the rehabilitated areas compared with the adjacent undisturbed areas. None of the mammals captured were considered dietary specialists. Because all of the mammal species caught in the undisturbed areas were present on the rehabilitated areas, we were unable to assess whether dietary requirements influenced mammals colonization of rehabilitated areas.

Ten of the 51 reptile species were dietary specialists (Table 6). Five of the 10 reptile dietary specialist species caught in the undisturbed areas were caught on rehabilitated areas. Dietary specialists were significantly less frequent ($\chi^2_1 = 20.7$, $P < 0.05$) on the rehabilitated areas than on the adjacent undisturbed areas. When the frequency of reptiles in each of three trophic groups was compared between the undisturbed areas and the rehabilitated areas, there was no significant difference ($\chi^2_2 = 0.21$, $P = 0.90$). Five of the dietary specialists caught in the undisturbed areas were in low numbers [*Pygopus lepidopodus* (1), *Brachyurophis semifasciata* (4), *Simoselaps bertholdi* (3), *Ramphotyphlops bituberculatus* (1) and *Lialis burtonis* (1)], which precluded drawing sensible conclusions about their presence or absence on rehabilitated areas. However, *Rhynchoedura ornata* (0/56), *Ramphotyphlops australis* (1/14), *Moloch horridus* (2/11), *Ramphotyphlops hamatus* (4/40) and *Diplodactylus pulcher* (5/146) were caught in lesser numbers on the rehabilitated areas than on the adjacent undisturbed areas suggesting insufficient suitable prey were available to sustain higher numbers on rehabilitated areas, although there may have been other reasons for their low numbers (e.g., predation, insufficient suitable habitat, insufficient pressure for individuals to move on to rehabilitated areas). The reptile assemblage contained more dietary specialists and a greater spread in foraging strategies than the mammal assemblage, and was therefore considered a better bio-indicator of rehabilitation success in the Ora Banda region.

Population fluctuation, reproductive rate and signal–to–noise ratio (criterion H)

Species that display significant year-to-year fluctuations in population size due to environmental factors that are unrelated to changes in the rehabilitation programme (e.g., rainfall) can confound the analysis and understanding of succession processes in rehabilitated areas. For example, elsewhere in Australia, rodent populations have been shown to fluctuate significantly in response to environmental conditions unrelated to the rehabilitation programme because they can have multiple clutches in a year (Newsome and Corbett 1975; Predavec 1994; Dickman *et al.* 1995). In contrast, only some reptile species are able to have multiple clutches in a single year (e.g., *Pogona minor*, Thompson and Thompson 2003; some *Ctenotus* spp., James 1991a,b).

Variations in catch rates on a daily or seasonal basis due to variables unrelated to rehabilitation progress (e.g., ambient temperature, humidity or moon phase) can also confound the analysis and understanding of succession processes. Our data showed significant seasonal and year-to-year fluctuations in mammal species abundance (e.g., *Mus musculus*, *Sminthopsis crassicaudata*, *Cercartetus concinnus*; Fig. 5). There were notable high catches during the warmer months for *C. concinnus* in April 2002, *S. crassicaudata* in December 2001 and 2002, and *M. musculus* in September and December 2000, and April 2001. The number of *S. crassicaudata* caught in December 2000 and 2001 were higher largely as a result of a higher number of weaned juveniles being caught. The capture rates for *Pseudomys bolami*, *P. hermannsburgensis* and *Sminthopsis dolichura* showed no consistent pattern and were influenced by other environmental variables.

There were obvious fluctuations in the number of reptiles caught on a seasonal basis (Fig. 6) because most reptiles are inactive during the cooler months, but year-to-year variations for December and January also indicated considerable fluctuations in catch rates, which we interpreted as partly a consequence of changes in density and sampling error. The magnitude of year-to-year variations for reptiles was less than for mammals. Our data indicate both assemblages display daily, seasonal and year-to-year variations in capture rates, with reptiles showing a little less variation when compared on a year-to-year basis for the same season. We concluded that this was not a particularly useful criterion to assess which of the two assemblages was the better bio-indicator.

Colonizing capacity (criterion I)

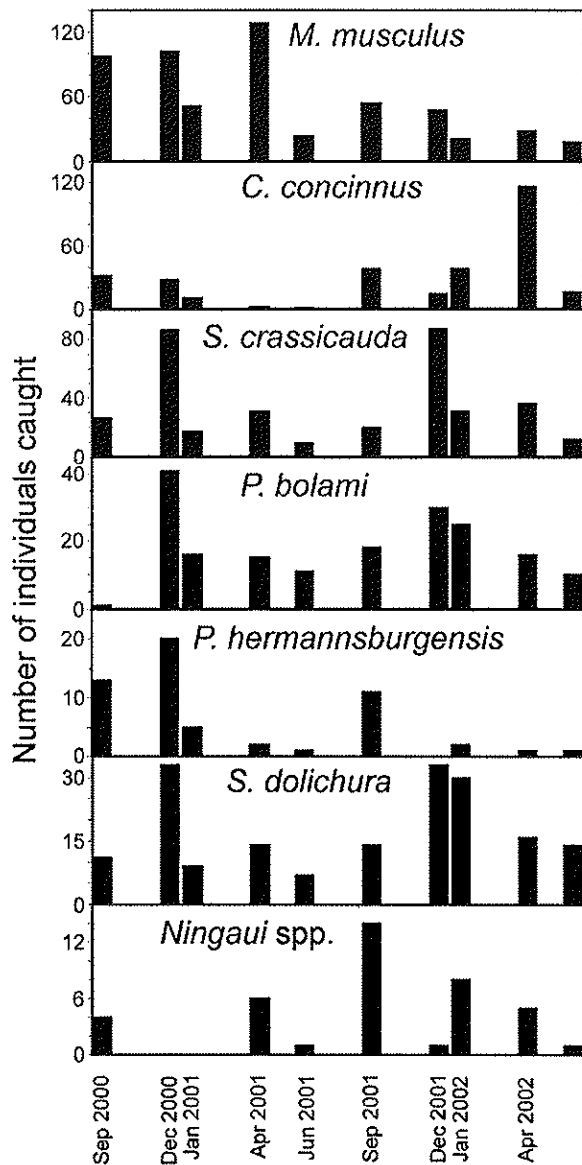To be useful as bio-indicators of rehabilitation progress, taxa must move into rehabilitated areas

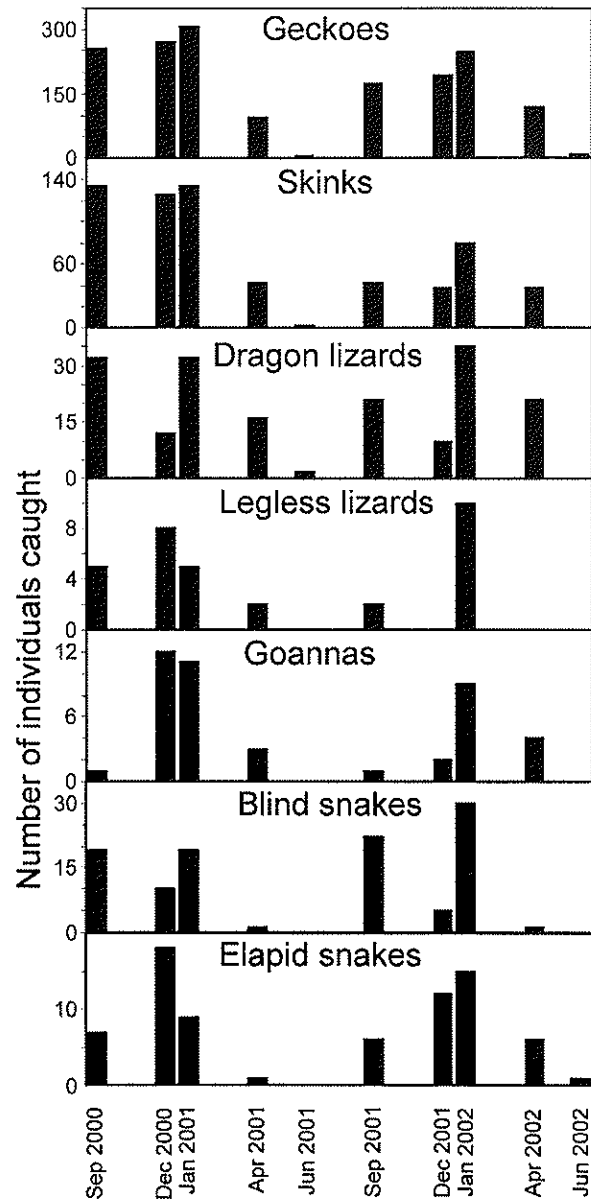Fig. 5. Seasonal changes in the relative abundances of mammal species.

Fig. 6. Seasonal variations in the relative abundances of reptile families.

when the appropriate habitat niches become available. There is a growing body of data that indicates that both reptile and mammal species will colonize an area after a major disturbance (e.g., fire, agriculture or mining; Fox and McKay 1981; B. J. Fox 1983, 1996; Twigg and Fox 1991; Halliger 1993; Pianka 1996). Walker et al. (1986) showed that some mammals and reptiles will readily cross rehabilitated area perimeter roads, non-rehabilitated areas and scale 65 m high slopes that are devoid of plant life to move into rehabilitated areas. Twigg et al. (1989) and Wilson and Friend (1999) suggested that for small mammals, particularly after wildfires, colonization into disturbed areas was closely related to successional changes in the vegetation, with both structure and floristic pattern being important. Given that reptiles partition the

environment into multidimensional niches (e.g., space, time, diet, activity period; Pianka 1986), and many species have specialized requirements, a diverse range of habitat niches will be required before the complete suite of the taxa can successfully invade the rehabilitated site from the adjacent undisturbed area, they would be the preferred bio-indicator assemblage.

Fox and his colleagues (Fox and Fox 1978, 1984; Twigg et al. 1989; B. J. 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. Our data indicate that all mammal species returned to rehabilitated mine sites within 6–8 yrs, long before the vegetation on rehabilitated areas was similar to that in the undisturbed

areas. Our capture rates indicated that *M. musculus* and *S. crassicaudata* were more abundant on rehabilitated areas than the adjacent undisturbed areas suggesting that the more open and less mature habitat on rehabilitated areas better suited their needs or there was less competition for resources.

Although there is a paucity of long-term chronosequence data for reptile movement into rehabilitated areas, the available data suggests 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). Our data indicate fewer reptile species were caught on rehabilitated areas than in the adjacent undisturbed areas, even thought there was a higher trapping effort on the rehabilitated areas than the adjacent undisturbed areas (5 040 vs 3 360 pit-trap days; Fig. 2). These data suggest that because the colonization of the complete suite of reptile species is spread over a longer period, most probably because of the need for a greater range of specific niches to develop (e.g., accumulated ground litter, hollow trees, decaying logs), this assemblage is a better bio-indicator of rehabilitation success than mammals using this criterion.

Succession processes and hierarchical suite of bio-indicators (criterion J)

Assemblages that display some hierarchical structure in their colonization of an area are more useful as bio-indicators; that is, there is an established sequence for species colonizing rehabilitated areas, and this sequence is linked with the various stages in the development of the vegetation community. Fox (1996), in his summary of many years work on small-mammal community succession into disturbed areas in eastern Australia, suggested that it takes 10–20 years for the abundances of mammal species to reach those in control areas, and there is an evolving pattern that will eventually enable us to understand this process. Twigg and Fox (1991) reported that reptiles are slower than mammals to colonize rehabilitated areas with species abundances being related to vegetation parameters such as patchiness, live shrub cover and plant diversity. 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. Our data indicate that representatives of all mammal species caught in the adjacent undisturbed areas were present on the rehabilitated areas.

Twenty-eight of the 46 species of reptiles caught in the adjacent undisturbed areas had already colonized the five rehabilitated areas we monitored. For eight reptile species (*Ctenophorus scutulatus, Delma australis, Cyclodomorphous melanops elongatus, Egernia inornata, Ctenotus uber, Lerista picturata, Ctenotus atlas, Rhynchoedura ornata*) we caught 10 or more individuals in the undisturbed areas and none on the rehabilitated areas, and for a further four species (*Rampho-typhlops australis, Cryptoblepharus plagiocephalus, Egernia depressa, Diplodactylus maini*) we caught 14 or more individuals in the undisturbed areas and only one on the rehabilitated areas. These data suggest that these species maybe the late colonizers of rehabilitated areas, but further research is required before we can draw strong conclusions as to why these species arrive late in the succession process.

For this criterion, it appears that both assemblages might have a succession sequence; however, there was inadequate data, particularly for reptiles, to draw strong conclusions.

Sensitivity to appropriate environmental changes and response rate suitable for intended application (criterion K)

Mine site rehabilitation in the goldfields of WA typically passes through a number of stages (geotechnical development to the placement of "topsoil", followed by ripping, then seeding and planting of vegetation; Nichols *et al.* 1985). As vegetation matures it provides greater canopy cover, leaf litter and decaying organic matter that provide shelter and food for invertebrates and vertebrates, allowing vertebrate fauna to colonize from adjacent areas. The presence and abundance of plant species and substrate characteristics in rehabilitated mining areas are associated with mammal and reptile species richness and abundance (Fox and Fox 1978, 1984; Twigg and Fox 1991; Brown 2001; Taylor and Fox 2001).

It might be expected that herbivorous fauna could generally colonize at an earlier stage in the rehabilitation process than the omnivores or carnivores, as they are not dependent of the presence of invertebrates and vertebrates as a food source. We could not test this as all of the mammal species caught in the undisturbed areas were present on the rehabilitated areas, and the number of carnivorous reptiles caught in the undisturbed areas was very low for most species except *Parasuta monachus*, which accounted for 15 of the 28 carnivores caught. It was expected that vertebrate carnivores and some other niche specialists would be late colonizers as they are in the higher trophic levels or require niches that are linked with a maturing rehabilitated area (e.g., *Simoselaps bertholdi*; needs both organic matter, leaf litter or soft surface soil and the presence of small lizards, as it is a fossorial vertebrate carnivore). We caught none of the

carnivorous *Pseudonaja modesta, Suta fasciata, Simoselaps bertholdi* and *Brachyurophis semifasciata* on the rehabilitated areas, which may suggest that conditions were not suitable, or alternatively, conditions were suitable and they had yet to colonize the available niches. Little is currently known about how mammals and reptiles respond to changes to various types of disturbance, or stages in the rehabilitation process. Therefore, we rated this criterion as being not very useful in determining which of the two assemblages was the better bio-indicator of rehabilitation success. This is likely to be a fertile area for future research.

Adaptive management potential (criterion L)

Bio-indicators can have multiple purposes. In addition to monitoring rehabilitation progress, a useful bio-indicator can provide management with information on how to increase the rate of progress in creating a near-natural, functional ecosystem by identifying niches that either are not being occupied or are not yet available. For example, the absence of specialist termite feeders might indicate the absence of dead trees able to support large termite colonies. The more plastic behaviour of mammals compared with reptiles, and the lower proportion of dietary and habitat specialists in the mammal assemblage compared with reptiles at Ora Banda (see discussion above) means that reptiles perform better as bio-indicators than mammals on this criterion.

Taxonomic status (criterion M)

With a little practice we could accurately identify all 51 species of the reptiles caught using keys provided by Storr et al. (1983, 1990, 1999, 2002). Where there was some doubt about the identity of an individual we deposited the specimen as a voucher with WAM to check or verify our identification in the field.

Eleven species of mammals were caught. Seven were relatively easily identified using the descriptive information contained in Strahan (2000) and Menkhorst and Knight (2001), and vouchered individuals with WAM. We found it impossible to confidently differentiate between *Ningaui yvonneae* and *N. ridei*, although both species were present at a number of our sites, as verified by vouchered specimens. Other than for individuals that we vouchered, we were forced to record *Ningaui* sp. when we pit-trapped one of these small dasyurids. We also had difficulty distinguishing *Pseudomys bolami* and *P. hermannsburgensis*. Kitchener et al. (1984) and Strahan (2000) acknowledged that these species are difficult to distinguish. Based on the criterion of being able to identify individuals in the field, reptiles are a better bio-indicator than mammals.

Trap-ability of assemblages (criterion N)

Pit-trapping is the normal method used to sample an area for small vertebrate species (Pianka 1986; Morton et al. 1988; Dickman et al. 1991; Rolfe and McKenzie 2000; Read and Moseby 2001), but this strategy is routinely supplemented with cage and Elliott traps, particularly for terrestrial mammals, and general searching of an area. Specialist searches and trapping strategies are routinely used for flying (e.g., bats) and arboreal species of mammals. There is a paucity of data on the trap-ability of various taxa. Bos (1999), for example, was one of the few to provide data and comment on the response of *Ningaui yvonneae* to pit-fall drift fences.

Moseby and Read (2001) reported that more trap-days were required to adequately sample mammal species than reptiles in arid areas as their distributions were extremely patchy and their activity patterns not as temperature dependent. Contrary to Moseby and Read (2001), we found the trapping effort required to catch the total number of pit-trappable mammal species at any of our Ora Banda sites was considerably less than to catch all the reptile species (Table 4). Inadequate data and the complexity of a comparative analysis rendered this criterion ineffective in determining which of the two assemblages was the better bio-indicator of rehabilitation success.

Field costs (criterion O)

Field costs are a practical issue that needs to be considered in determining which of the two assemblages are more useful. Using only pit-traps as the trapping strategy it was more expensive to adequately survey for reptiles than mammals.

Expertise to identify species (criterion P)

Most field surveys of fauna in the mining industry in WA are conducted by consultants, who regularly employ young biological science graduates to do much of the fieldwork. Taxonomic keys are available for most species of reptiles in Western Australia (Storr et al. 1983, 1990, 1999, 2002). There is no diagnostic key(s) available to distinguish and identify small WA mammals. This is a major deterrent to using small mammals as bio-indicators. Strahan (2000) and Menkhorst and Knight (2001) provide species descriptions. Both texts indicate similar species and offer useful suggestions on how similar species might be differentiated. Our experience in working with more than 40 volunteers who assisted with the Ora Banda field surveys, many of whom were undergraduate or graduate students studying biological or environmental sciences, was that most were able with some guidance and training to identify all of the reptile species, but almost all had difficulty with some of the mammal species.

Relative importance of assessment criteria

Selection of assessment criteria will affect the analysis and the outcome of the assessment, and researchers and practitioners may select different criteria because their needs are different. Similarly, the weighting attributed to each of the criterion would no doubt vary based on the user's context. In our assessment of the importance of each criterion, we ranked taxonomic status very high along with the easy of identifying individuals in the field. Unless pit-trapped individuals can be accurately identified in the field it would be impossible to use either taxa as bio-indicators. From a field practitioner's (e.g., mine site environmental officer) perspective the practical criteria (e.g., taxonomic status, trap-ability and costs) and usefulness of the criteria as a management tool would carry a heavy weighting. The information content group of criteria are very dependent on the available knowledge about each species ecology and natural history. This knowledge varies among taxa and among biogeographic areas and is influenced by previous research activity in the area. Species richness and relative abundance are probably the two most important and useful criteria from the information content group and both can be accurately assessed with sufficient trapping effort. In our assessment, reptiles generally performed better than mammals across the range of criteria we selected and therefore we believe our conclusions are reasonably robust from a researcher's and a practitioner's perspective.

Other researchers have used invertebrates, particularly ants, as bio-indicators of rehabilitation success. It would be interesting to undertake a comparison of reptiles and invertebrates as bio-indicators. If such an analysis used similar criteria to that described above, then this might lead to a better understanding of which criteria are the more meaningful and useful. The use of other taxa such as invertebrates or birds might also introduce additional or alternative assessment criteria, which would broaden the scope of the assessment and potentially make it more robust.

Method of capture of bio-indicator species

There are few comparative data for measuring success or bias using trapping methods such as funnel traps, wire cage traps, hand-foraging, hair traps, road transects, spotlighting, snare traps, artificial shelters, adhesive traps, pit-traps and scat analysis. One of the most comprehensive comparisons of various techniques for surveying ground-dwelling and arboreal mammals was reported by Catling et al. (1997). They reported that no single strategy proved to be acceptable for identifying the majority of species in the forested areas, making comparison among trapping strategies problematic.

If pit-trapping captures are biased toward a particular bio-indicator assemblage then this would affect the assessment of the usefulness of the criteria. For example, we know that PVC buckets catch proportionally more reptiles than PVC pipes, and pipes catch more small mammals than buckets (Thompson et al., in press). We now also routinely use funnel traps as part of our trapping strategy because our (unpubl.) data indicate that funnel traps catch proportionally more large snakes and widely foraging Ctenotus spp. than do pit-traps. We have also found that Elliott traps, which are a commonly used method for fauna trapping small vertebrates, particularly by environmental consultants in preparing environmental impact and habitat assessments, catch a different component of the small vertebrate assemblage than either funnel traps or pit-traps. These data would therefore suggest the choice of bio-indicator is significantly influenced by the trapping protocols that are to be used or vice-versa. We believe the usefulness of a bio-indicator is therefore trap-type specific.

REFERENCES

Andersen, A. N., 1993. Ants as indicators of restoration success following mining in northern Australia. *Rest. Ecol.* **Sept.**: 156–58.

Andersen, A. N., Hoffmann, B. D. and Somes, J., 2003. Ants as indicators of minesite restoration: community recovery at one of eight rehabilitation sites in central Queensland. *Ecol. Man. Rest.* **4 Supp.**: S12–9.

Anderson, L. and Burgin, S., 2002. Influence of woodland remnant edges on small skinks (Richmond, New South Wales). *Aust. Ecol.* **27**: 630–37.

Andersen, A. N., Fisher, A., Hoffmann, B. D., Read, J. L. and Richards, R., 2004. Use of terrestrial invertebrates for biodiversity monitoring in Australian rangelands, with particular reference to ants. *Aust. Ecol.* **29**: 87–92.

Bamford, M. J., 1980. Aspects of the Population Biology of the Bobtail Skink, *Tiliqua rugosa* (Gray). Murdoch University, Perth, Australia. Unpublished Honours Thesis.

Bomford, M., 1987. Food and reproduction of wild house mice I. Diet and breeding seasons in various habitats on irrigated cereal farms in New South Wales. *Aust. Wildl. Res.* **14**: 183–96.

Bos, D. G., 1999. Observations of the response of *Ningaui yvonneae* (Marsupialia: Dasyuridae) to pit-fall drift fences. *Aust. Mammal.* **21**: 143–47.

Bradford, D. F., Franson, S. E., Neale, A. C., Heggem, D. T., Miller, G. R. and Canterbury, G. E., 1998. Bird species assemblages as indicators of biological integrity in Great Basin Rangeland. *Envir. Monit Assess.* **49:** 1–22.

Brown, G. W., 2001. The influence of habitat disturbance on reptiles in a Box-Ironbark eucalypt forest of south-eastern Australia. *Biodiv. Cons.* **10:** 161–76.

Bull, C. M., 1987. A population study of the viviparous Australian lizard, *Trachydosaurus rugosus* (Scincidae). *Copeia* **1987:** 749–57.

Bull, C. M. and Freake, M. J., 1999. Home-range fidelity in the Australian sleepy lizard, *Tiliqua rugosa*. *Aust. J. Zool.* **47:** 1125–132.

Bustard, D. R., 1970. Australian Lizards. Collins, Sydney.

Bustard, H., 1968. The ecology of the Australian gecko *Heteronotia binoei* in northern New South Wales. *J. Zool. Lond.* **156:** 483–97.

Catling, P. C., Burt, R. J. and Kooyman, R., 1997. A comparison of techniques used in a survey of the ground dwelling and arboreal mammals in forests in north-eastern New South Wales. *Wildl. Res.* **24:** 417–32.

Chapman, A. and Dell, J., 1985. Biology and zoogeography of the amphibians and reptiles of the Western Australian wheatbelt. *Rec. West. Aust. Mus.* **12:** 1–46.

Cockburn, A., 1981. Diet and habitat preference of the silky desert mouse, *Pseudomys apodemoides* (Rodentia). *Aust. Wildl. Res.* **8:** 475–97.

Cogger, H. G., 1992. Reptiles and Amphibians of Australia. Reed, Sydney.

Davey, H., 1923. The Moloch lizard, *Moloch horridus*, Gray. *Vic. Nat.* **40:** 58–60.

Delean, S. and Harvey, M., 1981. Some observations on the knob-tailed gecko, *Nephrurus laevissimus* in the wild. *Herpetofauna* **13:** 1–3.

Dickman, C. R., Henry-Hall, N. J., Lloyd, H. and Romanow, K. A., 1991. A survey of the terrestrial vertebrate fauna of Mount Walton, western goldfields, Western Australia. *West. Aust. Nat.* **18:** 200–6.

Dickman, C. R., Predavec, M. and Downery, F., 1995. Long-range movements of small mammals in arid Australia: implications for land management. *J. Arid Envir.* **31:** 441–52.

Dubas, G. and Bull, C. M., 1991. Diet choice and food availability in the omnivorous lizard, *Trachydosaurus rugosus*. *Wildl. Res.* **18:** 147–55.

Fergusson, B. and Algar, D., 1986. Home range and activity patterns of pregnant skinks, *Tiliqua rugosa*. *Aust. Wildl. Res.* **13:** 287–94.

Fitzgerald, M., 1983. Some observations on the reproductive biology of the common scaly-foot *Pygopus lepidopodus*. *Herpetofauna* **14:** 79–82.

Fox, B., 1997. The distribution of fauna in natural and disturbed landscapes in relation to appropriate habitat. Paper presented at the Fauna Habitat Reconstruction after Mining Workshop 10–11 October, Adelaide, South Australia.

Fox, B. J., 1979. An objective method of measuring the vegetation structure of animal habitats. *Aust. Wildl. Res.* **6:** 297–303.

Fox, B. J., 1983. Mammal species diversity in Australian heathlands: the importance of pyric succession and habitat diversity. Pp. 473–89 *in* Mediterranean-type Ecosystems: The Role of Nutrients Vol. 43 ed by F. J. Kruger, D. T. Mitchell and J. U. M. Jarvis. Springer-Verlag, Berlin.

Fox, B. J., 1990. Changes in the structure of mammal communities over successional time scales. *Oikos* **59:** 321–29.

Fox, B. J., 1996. Long-term studies of small-mammal communities from disturbed habitats in Eastern Australia. Pp. 467–501 *in* Long-term Studies of Vertebrate Communities ed by M. L. Cody and J. A. Smallwood. Academic Press, San Diego.

Fox, B. J. and Fox, M. D., 1978. Recolonisation of coastal heath by *Pseudomys novaehollandiae* (Muridae) following sand mining. *Aust. J. Ecol.* **3:** 447–65.

Fox, B. J. and Fox, M. D., 1984. Small-mammal recolonisation of open-forest following sand mining. *Aust. J. Ecol.* **9:** 241–52.

Fox, B. J. and McKay, G. M., 1981. Small mammal responses to pyric successional changes in eucalypt forest. *Aust. J. Ecol.* **6:** 29–41.

Fox, J. E. D., 1997. Fauna habitat reconstruction after mining. Paper presented at the Fauna Habitat Reconstruction after Mining conference, 10–11 October, Adelaide, Australia.

Gillam, M. W., 1979. The genus *Pseudonaja (Serpentes: Elapidae)* in the Northern Territory. Territory Parks and Wildlife Commission, Research Bulletin No 1, Darwin, Australia.

Green, B. and King, D., 1978. Home range and activity patterns of the sand goanna, *Varanus gouldii* (Reptilia: Varanidae). *Aust. J. Wildl. Res.* **5:** 417–24.

Greer, A. E., 1989. The Biology and Evolution of Australian Lizards. Surrey Beatty & Sons, Chipping Norton.

Greer, A. E., 1997. The Biology and Evolution of Australian Snakes. Surrey Beatty & Sons, Chipping Norton.

Halliger, M., 1993. Reptiles on regenerating mine sites in western New South Wales. Pp. 327–32 *in* Herpetology in Australia: a Diverse Discipline ed by D. Lunney and D. Ayers. Royal Zoological Society of New South Wales, Sydney.

Henle, K., 1989. Ecological segregation in an assemblage of diurnal lizards in arid Australia. *Acta Ecologica/ Ecologia Generalis* **10:** 19–35.

Henle, K., 1990a. Population ecology and life history of the arboreal gecko *Gehyra variegata* in arid Australia. *Herp. Monogr.* **1990:** 30–60.

Henle, K., 1990b. Population ecology and life history of three terrestrial geckos in arid Australia. *Copeia* **1990:** 759–81.

Hilty, J. and Merenlender, A. M., 2000. Faunal indicator assemblage selection for monitoring ecosystem health. *Biol. Cons.* **92:** 185–97.

How, R. A. and Kitchener, D. J., 1983. The biology of the gecko *Oedura reticulata* Bustard, in a small habitat isolate in the Western Australian Wheatbelt. *Aust. Wildl. Res.* **10:** 543–46.

How, R. A. and Shine, R., 1999. Ecological traits and conservation biology of five fossorial "sand-swimming" snake species (Simoselaps: Elapidae) in south-western Australia. *J. Zool. Lond.* **249:** 269–82.

How, R. A., Dell, J. and Wellington, B., 1990. Reproductive and dietary biology of *Nephrurus* and *Underwoodisaurus* (Gekkonidae) in Western Australia. *Rec. West. Aust. Mus.* **14:** 449–59.

Ireland, T. T., Wolters, G. I. and Schemnitz, S. D., 1994. Recolonization of wildlife on a coal strip-mine in northwestern New Mexico. *Southwestern Nat.* **39:** 53–57.

James, C. D., 1991a. Annual variation in reproductive cycles of scincid lizards *(Ctenotus)* in central Australia. *Copeia* **1991:** 744–60.

James, C. D., 1991b. Population dynamics, demography, and life history of sympatric scincid lizards (*Ctenotus*) in central Australia. *Herpetologica* **47**: 194–210.

James, C. D., Morton, S. R., Braithwaite, R. W. and Wombey, J., 1984. Dietary pathways through lizards of the Alligator Rivers region, Northern Territory. Supervising Scientist for the Alligator Rivers Region, Canberra.

Karr, J. R., Fausch, F. D., Angermeiser, P. L., Yant, P. R. and Schlosser, I. J., 1986. Assessing Biological Integrity in Running Waters: A Method and its Rationale. Illinois Natural History Survey Special Publication 5, Illinois.

Kelly, J. R. and Harwell, M. A., 1990. Indicators of ecosystem recovery. *Environ. Manag.* **14**: 527–45.

Kitchener, D. J., 1995. Southern *Ningaui*. Pp. 119–20 *in* The Mammals of Australia ed by R. Strahan. Reed, Sydney.

Kitchener, D. J., Adams, M. and Baverstock, P., 1984. Redescription of *Pseudomys bolami* Troughton 1932 (Rodentia: Muridae). *Aust. Mammal.* **7**: 149–59.

Kitchener, D. J., How, R. A. and Dell, J., 1988. Biology of *Oedura reticulata* and *Gehyra variegata* (Gekkonidae) in an isolated woodland of Western Australia. *J. Herpet.* **22**: 401–12.

Kotler, B., Dickman, C. and Brown, J., 1998. The effects of water on patch use by two Simpson Desert granivores (*Corvus coronoides* and *Pseudomys hermannsburgensis*). *Aust. J. Ecol.* **23**: 574–78.

Landres, P. B., Verner, J. and Thomas, J. W., 1988. Ecological uses of vertebrate indicator species: a critique. *Cons. Biol.* **2**: 316–28.

Letnic, M. I. and Fox, B. J., 1997. The impact of industrial fluoride fallout on faunal succession following sand mining of dry sclerophyll forest at Tomago, NSW. — I Lizard recolonisation. *Biol. Cons.* **80**: 63–81.

Mac Nally, R., Ellis, M. and Barrett, G., 2004. Avian biodiversity monitoring in Australian rangelands. *Aust. Ecol.* **29**: 93–99.

Majer, J. D., 1983. Ants: bioindicators of minesite rehabilitation. land-use, and land conservation. *Environ. Manag.* **7**: 375–83.

Majer, J. D., 1983/84. Recolonisation by ants in rehabilitated open-cut mines in northern Australia. *Reclam. Reveg. Res.* **2**: 279–98.

Majer, J. D., 1985. Recolonisation by ants on rehabilitated mineral sand mines on North Stradbroke Island, Queensland, with particular reference to seed removal. *Aust. J. Ecol.* **10**: 31–48.

Majer, J. D. and Beeston, G., 1996. The biodiversity integrity index: an illustration using ants in Western Australia. *Cons. Biol.* **10**: 65–73.

Majer, J. D. and Nichols, O. G., 1998. Long-term recolonisation patterns of ants in Western Australian rehabilitated bauxite mines with reference to their use as indicators of restoration success. *J. Appl. Ecol.* **35**: 161–82.

Martin, K., 1972. Captivity observations of some Australian legless lizards. *Herpetofauna* **5**: 5–6.

Maryan, B., 1984. Observation of active *Delma fraseri* during night time hours. *South Aust. Herpet. Group Newsl.* 1984(Feb): 2.

Mattiske Consulting Pty Ltd., 1995. Flora and Vegetation of the Cawse find area. Woodward-Clyde, Perth.

McKenzie, N. L. and Dickman, C. R., 1995. Wongaui *Ningaui*. Pp. 116 *in* The Mammals of Australia ed by R. Strahan. Reed, Sydney.

Menkhorst, P. W. and Knight, F., 2001. A Field Guide to the Mammals of Australia. Oxford University Press, Melbourne.

Miller, A. and Webb, P., 2001. Diet of house mice (*Mus musculus* L.) on coastal dunes, Otago, New Zealand. *NZ. J. Zool.* **28**: 49–55.

Monamy, V. and Fox, B. J., 2000. Small mammal succession is determined by vegetation density rather than time elapsed since disturbance. *Aust. Ecol.* **25**: 580–87.

Moro, D. and Morris, K. D., 2000. Movements and refugia of Lakeland Downs short-tailed mice, *Leggadina lakedownensis*, and house mice, *Mus domesticus*, on Thevenard Island, Western Australia. *Wildl. Res.* **27**: 11–20.

Morton, S. R., 1995. Fat-tailed dunnart. Pp. 129–31 *in* The Mammals of Australia ed by R. Strahan. Reed, Sydney.

Morton, S. R., Gillam, M. W., Jones, K. R. and Fleming, M. R., 1988. Relative efficiency of different pit-trapping systems for sampling reptiles in spinifex grasslands. *Aust. J. Wildl. Res.* **15**: 571–77.

Moseby, K. and Read, J. L., 1998. Population dynamics and movement patterns of Bolam's mouse, *Pseudomys bolami*, at Roxby Downs, South Australia. *Aust. Mammal.* **20**: 353–68.

Moseby, K. E. and Read, J. L., 2001. Factors affecting pitfall capture rates of small ground vertebrates in arid South Australia. II. Optimum pitfall trapping effort. *Wildl. Res.* **28**: 61–71.

Murray, B. and Dickman, C. R., 1994. Granivory and microhabitat use in Australian desert rodents: are seeds important? *Oecologia* **99**: 216–25.

Murray, B., Dickman, C. R., Watts, C. and Morton, S. R., 1999. The dietary ecology of Australian desert rodents. *Wildl. Res.* **26**: 421–37.

Newsome, A. E. and Corbett, L. K., 1975. Outbreaks of rodents in semi-arid and arid Australia: Causes, preventions and evolutionary considerations. Pp. 117–51 *in* Rodents in Desert Environments ed by I. Prakash and P. K. Ghosh. Junk, The Hague.

Nichols, O. G. and Bamford, M. J., 1985. Reptile and frog utilisation of rehabilitated bauxite minesites and dieback-affected sites in Western Australia's jarrah *Eucalyptus marginata* forest. *Biol. Cons.* **34**: 227–49.

Nichols, O. G., Carbon, B., Colquhoun, I., Croton, J. and Murray, N., 1985. Rehabilitation after bauxite mining in south-western Australia. *Landsc. Plan.* **12**: 75–92.

O'Connell, T. J., Jackson, L. E. and Brooks, R. P., 1998. The Bird Community Index: A Tool for Assessing Biotic Integrity in the Mid-Atlantic Highlands. Pennsylvania State University, University Park, Pennsylvania.

Orange, P., 1991. Notes on the diet of the yellow-faced whip snake *Demansia psammophis psammophis* in the Kambalda region of Western Australia. *Herpetofauna* **21**: 29–30.

Patchell, F. and Shine, R., 1986. Food habits and reproductive biology of the Australian legless lizards (Pygopodidae). *Copeia* **1986**: 30–39.

Perry, G., 1999. The evolution of search modes: ecological versus phylogenetic perspectives. *Am. Nat.* **153**: 98–109.

Pianka, E. R., 1969a. Habitat specificity, speciation, and species density in Australian desert lizards. *Ecology* **50**: 498–502.

Pianka, E. R., 1969b. Notes on the biology of *Varanus caudolineatus* and *Varanus gilleni*. *West. Aust. Nat.* **11**: 76–82.

Pianka, E. R., 1970. Notes on the biology of *Varanus gouldii flavirufus*. *West. Aust. Nat.* **11**: 141–44.

Pianka, E. R., 1971a. Notes on the biology of *Amphibolurus cristatus* and *Amphibolurus scutulatus*. *West. Aust. Nat.* 11: 36–41.

Pianka, E. R., 1971b. Notes on the biology of *Varanus tristis*. *West. Aust. Nat.* 11: 180–83.

Pianka, E. R., 1986. Ecology and Natural History of Desert Lizards: Analyses of the Ecological Niche and Community Structure. Princeton University Press, Princeton.

Pianka, E. R., 1994. Comparative ecology of *Varanus* in the Great Victoria Desert. *Aust. J. Ecol.* 19: 395–408.

Pianka, E. R., 1996. Long-term changes in lizard assemblages in the Great Victoria Desert: Dynamic habitat mosaics in response to wildfires. Pp. 191–215 *in* Long-term Studies of Vertebrate Communities ed by M. J. Cody and J. A. Smallwood. Academic Press, San Diego.

Pianka, E. R. and Giles, W. F., 1982. Notes on the biology of two species of nocturnal skinks, *Egernia inornata* and *Egernia striata*, in the Great Victoria desert. *West. Aust. Nat.* 15: 44–49.

Pianka, E. R. and Pianka, H. D., 1976. Comparative ecology of twelve species of nocturnal lizards (Gekkonidae) in the Western Australian desert. *Copeia* 1976: 125–42.

Predavec, M., 1994. Population dynamics and environmental changes during natural irruptions of Australian desert rodents. *Wildl. Res.* 21: 569–82.

Read, J. L., 1998. The ecology of sympatric scincid lizards (*Ctenotus*) in arid South Australia. *Aust. J. Zool.* 46: 617–29.

Read, J. L., 1999a. Birds, reptiles and ants as indicators of ecological impacts of mining and pastoralism at Olympic Dam in the Australian arid zone. University of New England, Armidale, NSW, Unpublished PhD Thesis

Read, J. L., 1999b. Longevity, reproductive effort and movements of three sympatric Australian arid zone gecko species. *Aust. J. Zool.* 47: 307–16.

Read, J. L., 2002. Experimental trial of Australian arid zone reptiles as early indicators of overgrazing by cattle. *Aust. Ecol.* 27: 55–66.

Read, J. L. and Moseby, K. E., 2001. Factors affecting pitfall capture rates of small ground vertebrates in arid South Australia. I. The influence of weather and moon phase on capture rates of reptiles. *Wildl. Res.* 28: 53–60.

Roberts, A. R., 1998. Ecophysiology of semi-arid geckos. Relationships between ecology and physiology in sympatric nocturnal geckos from a semi-arid sandplain habitat with particular emphasis on locomotion and thermal biology. The University of Western Australia, Perth. Unpublished PhD thesis.

Rolfe, J. K. and McKenzie, N. L., 2000. Comparison of methods used to capture herpetofauna: an example from the Carnarvon basin. *Rec. West. Aust. Mus. Supp.* 61: 361–70.

Shine, R., 1983. Food habits and reproductive biology of Australian elapid snakes of the genus *Denisonia*. *J. Herpetol.* 17: 171–75.

Shine, R., 1986. Food habits, habitats and reproductive biology of four sympatric species of varanid lizards in tropical Australia. *Herpetologica* 42: 346–60.

Shine, R., 1988. Food habits and reproductive biology of small Australian snakes of the genera *Unechis* and *Suta* (Elapidae). *J. Herpetol.* 22: 307–15.

Smith, L. and Chapman, A., 1976. Reptiles and frogs of Tarin Rock and North Tarin Rock reserves. *Rec. West. Aust. Mus. Supp.* 2: 85–86.

Smyth, M. and Smith, M., 1974. Aspects of the natural history of three Australian skinks, *Morethia boulengeri*, *Menetia greyii* and *Lerista bougainvillii*. *J. Herpetol.* 8: 329–35.

Storr, G. M., Smith, L. A. and Johnstone, R. E., 1983. Lizards of Western Australia II: Dragons and Monitors. Western Australian Museum, Perth.

Storr, G. M., Smith, L. A. and Johnstone, R. E., 1990. Lizards of Western Australia III. Geckos and Pygopods. Western Australian Museum, Perth.

Storr, G. M., Smith, L. A. and Johnstone, R. E., 1999. Lizards of Western Australia I. Skinks. Western Australian Museum, Perth.

Storr, G. M., Smith, L. A. and Johnstone, R. E., 2002. Snakes of Western Australia. Western Australian Museum, Perth.

Strahan, N. R., How, R. A. and Dell, J., 1998. Reproduction and diet in four species of burrowing snakes (*Simoselaps* spp.) from southwestern Western Australia. *Rec. West. Aust. Mus.* 19: 57–63.

Strahan, R., 2000. The Mammals of Australia. Reed, Sydney.

Swan, M., 1983. Notes on the half-girdled snake *Simoselaps semifasciatus* (Gunther). *Herpetofauna* 14: 94.

Taylor, J. E. and Fox, B. J., 2001. Disturbance effects from fire and mining produce different lizard communities in eastern Australian forests. *Aust. Ecol.* 26: 193–204.

Thompson, G., 1993. Daily movement patterns and habitat preferences of *Varanus caudolineatus* (Reptilia: Varanidae). *Wildl. Res.* 20: 227–31.

Thompson, G. and King, D., 1995. Diet of *Varanus caudolineatus* (Reptilia: Varanidae). *West. Aust. Nat.* 20: 199–204.

Thompson, G. G., 1994. Activity area during the breeding season of *Varanus gouldii* (Reptilia: Varanidae) in an urban environment. *Wildl. Res.* 21: 633–41.

Thompson, G. G., 1995. Foraging patterns and behaviours, body postures and movement speed for goannas, *Varanus gouldii* (Reptilia: Varanidae), in a semi-urban environment. *J. Roy. Soc. West. Aust.* 78: 107–14.

Thompson, G. G., 1996. Notes on the diet of *Varanus gouldii* in a semi-urban environment. *West. Aust. Nat.* 21: 49–54.

Thompson, G. G., de Boer, M. and Pianka, E. R., 1999. Activity areas and daily movements of an arboreal monitor lizard, *Varanus tristis* (Squamata: Varanidae), during the breeding season. *Aust. J. Ecol.* 24: 117–22.

Thompson, G. G. and Pianka, E. R., 1999. Reproductive ecology of the black-headed goanna *Varanus tristis* (Squamata: Varanidae). *J. Roy. Soc. West. Aust.* 82: 27–31.

Thompson, S. A., 2003. Reproductive observations of a Thorny Devil, *Moloch horridus*, in a natural semi-arid environment. *West. Aust. Nat.* 24: 73–78.

Thompson, S. A. and Thompson, G. G., 2003. The western bearded dragon, *Pogona minor* (Squamata: Agamidae): An early lizard colonizer of rehabilitated areas. *J. Roy. Soc. West. Aust.* 86: 1–6.

Thompson, S. A., Thompson, G. G. and Withers, P. C. In press. Influence of pit-trap type on the interpretation of fauna diversity. *Wildlife Research*.

Twigg, L. E. and Fox, B. J., 1991. Recolonisation of regenerating open forest by terrestrial lizards following sand mining. *Aust. J. Ecol.* 16: 137–48.

Twigg, L. E., Fox, B. J. and Jia, L., 1989. The modified primary succession following sand mining: A validation of the use of chronosequence analysis. *Aust. J. Ecol.* 14: 441–47.

Walker, K. J., Osborne, J. M. and Dunlop, N., 1986. Vertebrate colonisation after revegetation of a rehabilitated iron ore waste dump, Newman, W.A. Paper presented at the Environmental Workshop — 1986 papers, Launceston.

Watts, C., 1995. Mitchell's Hopping-mouse. Pp. 579–80 in The Mammals of Australia ed by R. Strahan. Reed, Sydney.

Webb, G. A., 1983. Diet in a herpetofaunal community on the Hawkesbury sandstone formation in the Sydney area. *Herpetofauna* 14: 87–91.

Webb, J. and Shine, R., 1993. Dietary habits of Australian blind snakes (Typhlopidae). *Copeia* 1993: 762–70.

Whitehead, P., Woinarski, J., Fisher, A., Faensham, R. and Beggs, K., 2001. Developing an Analytical Framework for Monitoring Biodiversity in Australia's Rangelands. Report to the National Land and Water Resources Audit. Tropical Savannas Cooperative Research Centre, Darwin.

Wilson, B. A. and Friend, G. R., 1999. Responses of Australian mammals to disturbance: A review. *Aust. Mammal.* 21: 87–105.

Withers, P. C. and Bradshaw, S. D., 1995. Water and energy balance of the thorny devil *Moloch horridus*: is the devil a sloth? *Amphibia-Reptilia* 16: 47–54.

Withers, P. C. and Dickman, C. R., 1995. The role of diet in determining water, energy and salt intake in the thorny devil *Moloch horridus* (Lacertilia: Agamidae). *J. Roy. Soc. West. Aust.* 78: 3–11.

Mammals or reptiles, as surveyed by pit-traps, as bio-indicators of rehabilitation success for mine sites in the goldfields region of Western Australia?

G. G. Thompson and S. A. Thompson