Diversity and abundance of pit-trapped reptiles in Australian arid and mesic habitats: Biodiversity for Environmental Impact Assessments

GRAHAM G. THOMPSON[1*], SCOTT A. THOMPSON[2], PHILIP C. WITHERS[3] and ERIC R. PIANKA[4]

Based on pit-trapping data for reptile assemblages from mesic, semi-arid and arid Australian sites, we examined species richness, diversity and evenness for general patterns. Reptile assemblages in Australian arid and semi-arid areas are generally species rich, have a high diversity, and have a high proportion of species that are rarely caught. Skinks are generally the most abundant taxa, followed by geckos and agamids. Varanids, elapid and blind snakes are less frequently caught, and pygopods are seldom caught in pit-trapping programmes. However, there was considerable variability in the pattern of reptile assemblages across the Australian arid and semi-arid landscape, and even among closely located sites within the same soil and vegetation zones. A high proportion of arid and semi-arid reptile species are rarely caught in pit-traps. Western Australian Environmental Protection Authority's current requirements for assessing the effects of a potential disturbance, which are based on desktop study and small-scale field survey, are inadequate to describe biodiversity at the genetic, species and ecosystem levels, and also in terms of ecosystem function. If the Environmental Protection Authority considers rare species are an important component of the biodiversity of an area, then a greater level of trapping is required for the preparation of an environmental impact assessment than is generally occurring at present.

Key words: Diversity, Abundance, Reptiles, EIA, Australia, Pit-trapping.

INTRODUCTION

THE Environmental Protection Authority in Western Australia recently released its Position Paper No. 3, *Terrestrial Biological Survey as an Element of Biodiversity Protection* (2002), which indicates the extent of biological surveys required for each of the 26 Western Australian Interim Biogeographic Regions when preparing an environmental impact assessment. For developments that are rated as "high impact" in any region, a desktop survey, reconnaissance survey and a comprehensive flora and fauna survey are required. For developments rated as "moderate" or "low" impact, a desktop study, or a desktop study with a reconnaissance survey and a comprehensive flora and fauna survey, are required, depending on the region. The position paper goes on to indicate that the Environmental Protection Authority "expects proponents to ensure the terrestrial biological surveys provide sufficient information to address both biodiversity conservation and ecological function values . . ." (Environmental Protection Authority 2002).

Data often reviewed in a desktop study will include a checklist of rare or endangered species historically known to have been in the area (using the Department of Conservation and Land Management database) and a review of the Western Australian Museum species list for the area. Other sources of information include systematic surveys on a regional scale undertaken by government agencies (e.g., McKenzie *et al.* 1991, 2000; McKenzie and Hall 1992) or researchers (e.g., Pianka 1986, 1996). Are these data adequate to enable the Environmental Protection Authority to assess the impact of local level disturbances on the biodiversity of the area? If no field survey data exist for an area being reviewed and the museum records are poor, then how do proponents of a development assess the ecological significance or biodiversity value of the area from a desktop survey?

For sites with substantial data on species richness and abundance, a field survey is generally not required by the Environmental Protection Authority, and available data need to be interpreted in the context of the site's contribution to biodiversity and the importance of the ecosystem (Environmental Protection Authority 2002). An earlier Environmental Protection Authority preliminary position statement (Environmental Protection Authority 2000) was critical of the quality of environmental impact assessment reports submitted for its consideration, indicating "a lack of appropriate scale baseline information", "site-specific data

[1]Edith Cowan University, 100 Joondalup Drive, Joondalup, Western Australia, Australia 6027.
[2]Centre for Ecosystem Management, Edith Cowan University, 100 Joondalup Drive, Joondalup, Western Australia, Australia 6027.
[3]School of Animal Biology, University of Western Australia, Crawley, Western Australia, Australia 6009.
[4]Integrative Biology, University of Texas at Austin, Austin, Texas, 78712-1064, USA.
*Corresponding author.

being collected but not interpreted/analysed for biodiversity value", "lack of reference to current literature" and concluded that the "Environmental Protection Authority historically accepted substandard work". Even when a field survey was undertaken, the adequacy of the survey was such that the value and usefulness must be questioned (Thompson *et al.*, in press). So, how much useful data are available for proponents and their consultants?

There is a paucity of collated data on patterns of reptile fauna against which site-specific terrestrial fauna survey data can be evaluated. Baseline information and summarized literature that report on diversity and abundance across a range of habitats, or for a particular Western Australian Interim Biogeographic Regions, are generally not available for reptile assemblages. So, on what basis do proponents of a development judge species at a particular site to make a significant contribution to biodiversity or ecosystems? Obviously the presence of rare, endangered or range-restricted species would normally give a site special status, but a species does not have to be rare to make a significant contribution to biodiversity or to justify being of particular interest. Does high species richness or high abundance of particular taxa also indicate special status and, if it does, then what makes one site significant and another of less importance? These questions can best be addressed by proponents in the context of the "typical pattern of diversity and abundance" for the region. Is it possible to describe a typical pattern of diversity and abundance for undisturbed Australian habitats against which we can compare sites? Literature on this issue and the associated questions is scant.

Our study examined species richness and abundance of reptiles for a number of mesic, semi-arid and arid sites in Australia for general patterns. We used only pit-trap data, as this is the primary method for collecting reptiles for environmental impact assessments, although some consultants also use a range of other strategies such as raking and searching. For these latter methods, search effort is often difficult to quantify and experience can influence catch rates. We examined data for two bioregional scale studies (Carnarvon Basin and Lake Eyre Basin), and twelve landscape-local scale areas; two of these are the same area (Tanami Desert) but surveyed at different times and reported separately. In addition, we compare biotopes (homogenous habitat) within two landscape scale areas (Bungalbin and Ora Banda) to enable us to address questions about the extent of similarity of reptile assemblages within a landscape.

METHODS AND MATERIALS

We selected 14 study sites, 10 of which are from the literature and four of our own, all of which have collected a minimum of 800 individual reptiles during a pit-trapping programme. A minimum of 800 individuals was used to ensure sufficient reptiles were caught to enable reasonable estimates of diversity and abundance (Thompson *et al.*, in press). Many of the indices of diversity are influenced by species richness (Magurran 1988; Hayek and Buzas 1997) and estimates of species richness are influenced by survey effort (Thompson and Withers, in press). Surveyed habitats varied in size (1 ha to 75 000 km^2), and bioregional and landscape scale sites typically include a range of soil types and vegetation habitats. Selected sites are in mesic, semi-arid and arid areas of Australia (Fig. 1).

Site descriptions

Bioregional scale

Carnarvon Basin (surveyed by Rolfe and McKenzie 2000)

The Carnarvon Basin was the largest of the areas surveyed (26°0'S, 114°30'E; 75 000 km^2; Fig. 1). The Basin had relatively flat alluvial plains that dominated the study area, although there were uplands in the eastern section. The area was a complex mosaic of soils and vegetation, as might be expected for such a large area, and included woodlands associated with two relatively large ephemeral rivers, low red sand ridges vegetated with spinifex grasses and low shrubs, woodlands, coastal dunes and low-lying saline areas that support samphire and saltbush communities. Specimens were captured with 20 L PVC buckets and 125 mm PVC pipes with flywire drift-fences.

Lake Eyre South catchment area (surveyed by Read and Owens 1999)

This was a large study site (29°30'S, 136°30'E; 26 256 km^2; Fig. 1) that included cracking soils, sand dunes, gibber plains, rocky outcrops, chenopod shrubland and woodland. The major land use was pastoralism. Data were collected in two lines of six pitfall traps at 77 sites within the catchment during 1995.

Landscape scale

Redsands (authors' survey)

Redsands (28°12'S, 123°35'E; 1 km^2, Fig. 1) was in the Great Victoria Desert of Western Australia. It was characterized by red sand plains and long east-west sand ridges (Shephard 1995). The Redsands survey included the swale, base, slope

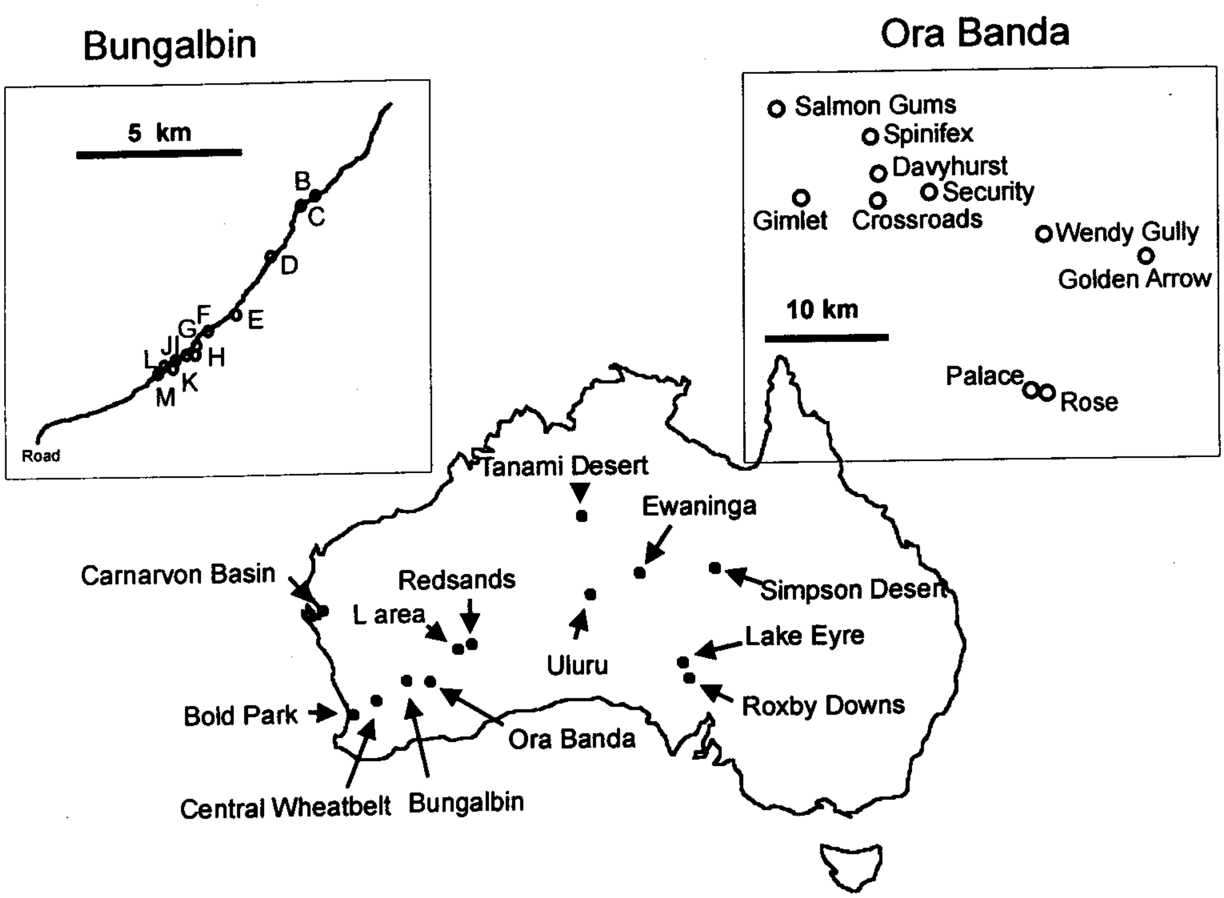

Fig. 1. Location of bioregional sites and the biotope sites at Bungalbin and Ora Banda.

and crest of sand ridges with most areas being vegetated with spinifex (*Triodia basedowii*), occasional large marble gum eucalypt trees (*Eucalyptus gongylocarpa*), and some scattered bushes (*Acacia aneura* and others) often in patches. All reptiles were caught in 20 L PVC buckets joined by flywire drift-fences located in the various habitats. All captured reptiles were removed. Trapping took place intermittently over a 10 year period.

Simpson Desert (surveyed by Downey and Dickman 1993)

This study site was located in southwestern Queensland (23°46'S, 138°28'E; Fig. 1). It was characterized by linear red sand ridges (up to 8 m, 0.6–1 km apart) vegetated with spinifex (*Triodia basedowi*) with the occasional shrub (*Acacia* spp.). Reptiles were caught in 20 L PVC buckets joined by flywire drift-fences. Twenty grids, each consisting of six trap lines of six traps, 20 m apart, were spaced between 0.6 and 2 km apart. Trapping was undertaken on 15 occasions between March 1990 and June 1993.

Bungalbin (authors' survey)

Bungalbin sandplain (30°24'S, 119°38'E; Fig. 1) was a gently undulating site, covered with small shrubs (predominantly *Melaleuca* spp. and *Acacia* spp.), sedges and perennial grass clumps of spinifex (*Triodia* spp.). Twelve sites (labelled B to M) located along a sand track, each containing five arrays of six pit-traps (150 mm PVC pipes; 30 in total per site), were sampled from December 1989 until April 2001 for periods of 3 to 20 days each spring-autumn when reptiles were active. The 12 sites were placed in different vegetation habitats within 10 km of each other (Fig. 1), and for the purposes of this analysis we considered each site a separate biotope. Other than vouchered specimens, most captured individuals were released. Recaptured reptiles were excluded from this data set.

Ora Banda (authors' survey)

Ora Banda (30°27'S, 121°4'E; Fig. 1) was on Archaen granites or gneisses 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.) through to dense shrubs (*Acacia* spp., *Atriplex* spp., *Allocasuarina* spp.). Our 10 study sites (Salmon Gums, Spinifex, Gimlet, Golden Arrow, Davyhurst, Security, Palace, Rose, Wendy Gully and Crossroads) were located within

50 km of each other (Fig. 1). Each site was located near the centre of a specific vegetation community. Each site was considered a separate biotope for the purposes of this analysis. Data were collected during 10 field trips between spring 2000 and winter 2002 using alternating 20 L PVC buckets and 150 mm PVC pipes joined by flywire drift-fences, with 48 pit-traps at each site. Recaptured reptiles were excluded from this data set.

Central Wheatbelt of Western Australia (surveyed by Smith *et al.* 1997)

Within the wheatbelt of Western Australia, numerous plots of remnant vegetation have been incorporated into a reserve system. This study site included eight of these remnant plots (1 680 km²) and an extensive area of a salt lake between Kellerberrin (31°38'S, 117°43'E) and Trayning (31°07'S, 117°47'E). The original vegetation was a complex mosaic of heath, shrublands and woodlands. Data were collected between 1987 and 1994 using 20 L PVC buckets, joined by a flywire drift-fence.

L Area (authors' survey)

Great Victoria Desert (GVD) L area (28°31'S, 122°46'E; Fig. 1) was typical western Great Victoria Desert habitat; flat, gently rolling, red sand plain, dominated by spinifex (*Triodia basedowii*), with large marble gum eucalypt trees (*Eucalyptus gongylocarpa*) and some scattered bushes (*Acacia aneura* and others). No sand ridges were nearby, but some gentle swales were present. Traps (20 L PVC buckets with flywire drift-fences) were run intermittently between September 1989 and December 1992. All reptiles caught were removed.

Tanami Desert A (surveyed by Morton *et al.* 1988)

This study site (20°32'S, 130°24'E; Fig. 1) was a flat sand plain dominated by spinifex (*Plectrachne schinzii*), with the composition of the grassland varying due to its fire history. Reptiles were caught using both PVC buckets and pipes during October and November 1985, and March and April 1986.

Tanami Desert B (surveyed by Hobbs *et al.* 1994)

This study site (20°32'S, 130°24'E; Fig. 1) was as described above. Reptiles were caught in 20 L PVC buckets with drift-fences during each autumn and spring between March 1987 and March 1990. Although it was not explicit in their article, it is presumed that the two Tanami study sites are similar if not the same.

Uluru (surveyed by Masters 1996)

This study site was 15 km west of Ayers Rock on the boundary of the Uluru National Park (25°17'S, 130°55'E; Fig. 1) and was transitional sand plain with heavy clayey sands. The dominant vegetation was spinifex (*Triodia basedowii*) with scattered shrubs (*Acacia* spp. and desert oaks). The site was burnt in 1976 and the data were collected between September 1987 and May 1990. Pit-traps were 20 L PVC buckets with drift-fences.

Ewaninga (surveyed by James 1989)

James (1989) described this site, 40 km south of Alice Springs (24°0'S, 133°54'E; Fig. 1), as irregular sand dunes (up to 7 m) covered with *Triodia* spp., *Plectrachne* spp. and a small number of shrubs (*Eucalyptus* spp. and *Acacia* spp.). Pit-traps were 20 L PVC buckets joined by drift-fences. Trapping was undertaken in both spring and autumn between September 1985 and April 1988.

Bold Park (surveyed by How 1998)

Bold Park (31°58'S, 115°42'E; Fig. 1) was a large (330 ha) remnant bushland on the Swan Coastal Plain in Western Australia. This study site consisted of four mesic habitats (coastal heath, *Dryandra sessilis* shrubland, *Banksia attenuata* and *B. menziesii* woodland, and *Eucalyptus gomphocephala* woodland) situated on the Quindalup Dune formation. This study site was dissimilar to the arid and semi-arid locations in inland Australia, but it provided an interesting contrast that enabled a comparison to be drawn between mesic and semi-arid habitats of similar latitude. The survey was undertaken between December 1986 and June 1993 using 175 mm PVC pipes joined by flywire drift-fences.

Roxby Downs (surveyed by Read 1995)

A one hectare chenopod shrubland near Roxby Downs (30°29'S, 136°53'E; Fig. 1) in arid South Australia was surveyed between January 1991 and June 1993, using 401 PVC pipes. No drift-fences were used in this study, but pits were placed at 5 m intervals in a square grid. The trapping area was in an interdunal swale that was dominated by the perennial shrubs, *Atriplex vesicaria* and *Maireana astrotricha*.

Data Analyses — Pit-trapping catches were tallied to calculate the total number of individuals caught, the total number of species, and the number and percentage of species in major taxonomic groups (Agamidae — agamids; Varanidae — varanids; Scincidae — skinks; Gekkonidae — geckos; Pygopodidae — pygopods; Typhlopidae — blind snakes; Elapidae — elapid snakes; Boidae — pythons). For each study site, the Shannon index (H: in using Species Diversity and Richness II software), α log series diversity index (Magurran 1988; using Species Diversity and Richness II software) and evenness index (E: Hayek and Buzas 1997; using Species Diversity and Richness II software) were calculated. The Shannon index was selected as it is relatively insensitive to sample size, it is commonly used, and it is easy to calculate (Magurran 1988; Magnussen and Boyle 1995; Hayek and Buzas 1997). The α log series diversity index was selected because it has good discriminating ability, it is based on relative abundance, and it is easy to calculate (Magurran 1988; Hayek and Buzas 1997). The E index was selected because of its general acceptance (Hayek and Buzas 1997). Shannon's index depends on two components, the number of species (S) and evenness (E). H can vary greatly when S is held constant because of differences in E. Conversely, H can vary greatly when E is held constant because of differences in S. Reptile assemblages for a site can therefore be adequately characterized by a combination of H, S and E (Hayek and Buzas 1997).

For the 12 biotopes within Bungalbin and 10 biotopes within Ora Banda landscape sites, the same range of diversity and evenness indices were calculated, along with the Morisita-Horn similarity index to compared sites (Magurran 1988) using *EstimateS* software (Colwell; http://viceroy.eeb.icon.edu/estimates). From a range of similarity indices, we selected the quantitative version of the Morisita-Horn similarity index based on Magurran (1988). Differences between observed values among sites for the α log series diversity index were tested using Chi-squared analysis (Magurran 1988). Estimated number of species in common among sites was calculated using the method outlined by Chao *et al.* (2000) using *EstimateS* software.

Rare species were defined in heterogenous sites as representing less than 0.5% of the total number of individuals caught. For the homogeneous sites at Ora Banda and Bungalbin, a species was defined as rare when less than 1% of the individuals caught belonged to that species, as sample sizes at some of the 22 biotope sites were insufficient to use the 0.5% criterion.

RESULTS

Heterogenous sites — Species richness was 66 (Lake Eyre) and 76 (Carnarvon Basin) for the two bioregional sites, and ranged from 26 (Bold Park) to 68 (Redsands) for the landscape-local scale sites (Table 1). There was no significant relationship between the percentage of rare species and the total number of individuals caught ($r = 0.49$, $p = 0.07$); however, if we relaxed the definition of rareness to 1% (as for homogenous sites) of total captures then there is a significant positive correlation ($r = 0.75$, $p < 0.05$) between percentage of rare species and total number of individuals caught. This is probably because the propensity to catch rare species increases with the number of individuals caught (Thompson *et al.*, in press). Overall, the least represented taxonomic groups were in ascending order pythons, blind snakes, elapid snakes, pygopods and varanids (Fig. 2). The most abundant taxonomic group was skinks, followed by geckos and agamids (Fig. 2). This pattern was reasonably consistent across all 14 study sites, with the exception of Ora Banda that had more geckos than any other taxonomic group (Fig. 2). Notably, no pygopods were caught at Roxby Downs, no elapid snakes were caught at the Simpson Desert site, and no blind snakes were caught at the Simpson Desert and Bungalbin sites. Bold Park had the lowest species richness, closely followed by Roxby Downs, and there was no correlation between species richness and total number of individuals caught ($r = 0.25$, $p = 0.38$). Diversity varied considerably for heterogenous sites. The Shannon index ranged from 1.7 to 3.6; α log series diversity index ranged from 4.1 to 17.3; evenness ranged from 0.32 to 0.69 (Table 1).

Species similarity was very high between the two Tanami Desert sites (0.98). Sites containing high, red sandy ridges (e.g., Redsands, Ewaninga, L area, Tanami Desert) generally had similarity scores greater than 0.4, otherwise species similarity was comparatively low (<0.4).

Homogenous sites — For the 12 homogeneous sites within the Bungalbin landscape, the taxonomic composition among sites varied and species richness ranged from 19 to 26 (Table 2). Overall, the most abundant taxonomic group was skinks, followed by agamids then geckos (Fig. 3). No blind snakes, and relatively few elapid snakes, varanids and pygopods were caught at Bungalbin. Although skinks were most abundant at a majority of sites, agamids were the most abundant taxonomic group at a quarter of the sites, and geckos were the most abundant taxonomic group at one site. The number of agamid species varied from 2 to 6, the number of skink species varied from 6 to 11, the number of gecko species from 5 to 8, and the number of pygopod species varied from 1 to 4. Between 17 and 50% of all species caught were rare. H ranged between 2.1 to 2.8, α log series diversity index ranged from 5.1 to 8.2, and E ranged from 0.55 to 0.77. The Morisita-Horn similarity index for Bungalbin sites ranged from 0.2 to 0.9 (Table 3), indicating that there was sufficient difference in vegetation and other niche related variables to significantly alter the composition of reptile assemblages although the sites were in close proximity on the same sand plain. Estimates of shared species (Table 3) for any site were generally between 18 and 30, with a few higher values.

Table 2. Number of reptile species and individuals caught, and the diversity and evenness values for each of the 12 pit-trap biotopes at Bungalbin.

	B	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*	*K*	*L*	*M*
Total No. individuals	300	196	262	238	193	145	278	308	305	201	210	175
Species richness (S)	23	26	25	23	23	24	25	24	23	24	19	20
Individuals												
Agamids	131	64	78	84	44	44	85	112	116	80	18	26
Varanids	9	2	6	1	1	3	3	1	3	6	5	4
Skinks	108	85	106	110	81	50	117	119	71	53	55	102
Geckos	36	41	67	31	65	45	65	69	112	60	126	42
Pygopods	11	4	4	9	2	2	7	7	1	2	4	1
Elapid snakes	5	0	1	3	0	1	1	0	2	0	2	0
Blind snakes	0	0	0	0	0	0	0	0	0	0	0	0
Species												
Agamids	4	6	3	3	3	4	4	3	3	3	2	3
Varanids	1	1	1	1	1	1	1	1	1	1	1	1
Skinks	8	11	10	8	11	11	10	10	9	11	6	9
Geckos	5	6	7	7	6	6	6	6	8	7	6	6
Pygopods	4	2	3	3	2	1	3	4	1	2	2	1
Elapid snakes	1	0	1	1	0	1	1	0	1	0	2	0
Blind snakes	0	0	0	0	0	0	0	0	0	0	0	0
Percentage of species												
Agamids	17.39	23.08	12.00	13.04	13.04	16.67	16.00	12.50	13.04	12.5	10.53	15.00
Varanids	4.35	3.85	4.00	4.35	4.35	4.17	4.00	4.17	4.36	4.17	5.26	5.00
Skinks	34.78	42.31	40.00	34.78	47.83	45.83	40.00	41.67	39.13	45.83	31.58	45.00
Geckos	21.74	23.08	28.00	30.43	26.09	25.00	24.00	25.00	34.78	29.17	31.58	30.00
Pygopods	17.39	7.69	12.00	13.04	8.70	4.17	12.00	16.67	4.35	8.33	10.53	5.00
Elapid snakes	4.35	0.00	4.00	4.35	0.00	4.17	4.00	0.00	4.35	0.00	10.53	0.00
Blind snakes	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
% Species <1%	30.43	30.77	20.00	17.39	21.74	33.33	32.00	50.00	34.78	20.83	21.05	25.00
Shannon diversity index (H)	2.34	2.61	2.70	2.50	2.83	2.59	2.40	2.07	2.37	2.63	2.02	2.31
Evenness (E)	0.63	0.71	0.73	0.68	0.77	0.70	0.65	0.56	0.64	0.71	0.55	0.63
α Log series diversity	5.81	8.04	6.79	6.28	6.82	8.19	6.66	6.09	5.78	7.10	5.08	5.82

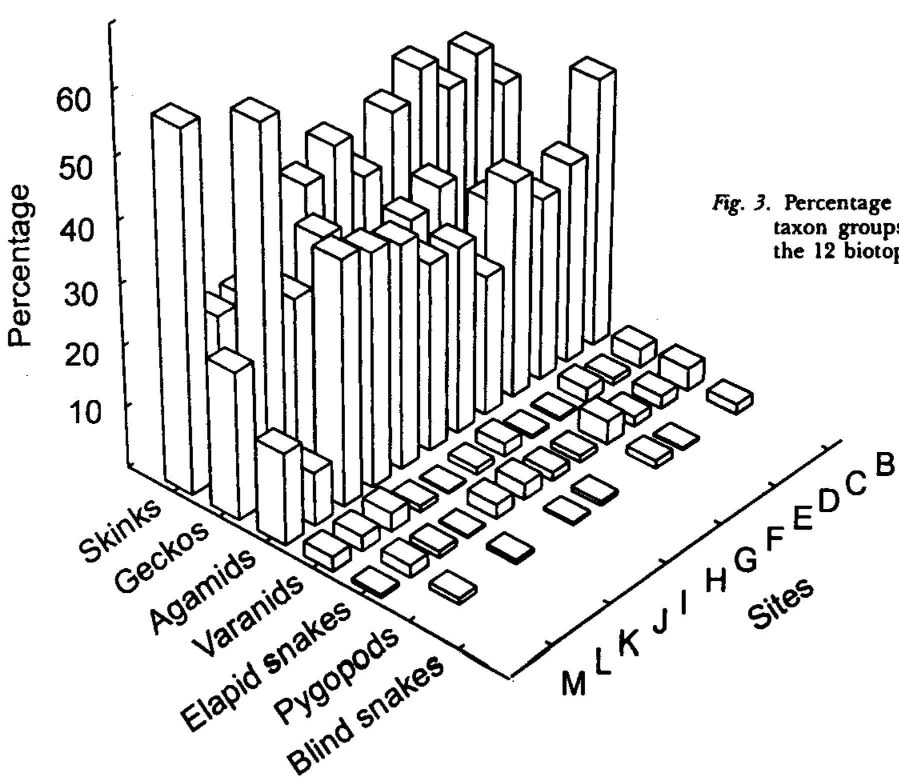

Fig. 3. Percentage of individuals for each of the taxon groups caught in pit-traps at each of the 12 biotopes at Bungalbin.

Table 3. Morisita-Horn similarity index for the 12 Bungalbin sites and an estimate of the shared species among sites in parenthesis.

Sites	B	C	D	E	F	G	H	I	J	K	L	M
Species richness	23	26	25	23	23	24	25	24	23	24	19	20
B		0.85 (22)	0.44 (22)	0.48 (19)	0.36 (18)	0.28 (16)	0.29 (26)	0.27 (42)	0.21 (20)	0.50 (24)	0.17 (18)	0.33 (16)
C			0.49 (18)	0.40 (20)	0.46 (22)	0.36 (27)	0.26 (27)	0.18 (30)	0.20 (23)	0.51 (24)	0.21 (16)	0.25 (18)
D				0.70 (21)	0.85 (25)	0.87 (25)	0.73 (30)	0.65 (35)	0.83 (23)	0.90 (21)	0.35 (18)	0.52 (23)
E					0.60 (22)	0.75 (27)	0.84 (28)	0.85 (40)	0.75 (22)	0.74 (22)	0.33 (18)	0.76 (22)
F						0.76 (30)	0.62 (30)	0.50 (49)	0.67 (19)	0.75 (22)	0.42 (19)	0.45 (26)
G							0.81 (26)	0.74 (23)	0.88 (23)	0.89 (23)	0.55 (18)	0.54 (26)
H								0.94 (27)	0.89 (27)	0.84 (23)	0.61 (20)	0.73 (24)
I									0.86 (31)	0.77 (36)	0.54 (18)	0.81 (26)
J										0.90 (18)	0.52 (17)	0.57 (20)
K											0.49 (17)	0.51 (20)
L												0.46 (16)

Table 4. Number of reptile species and individuals caught, and the diversity and evenness values for each of the 10 pit-trap biotopes at Ora Banda. C = Crossroads, D = Davyhurst, G = Gimlet, GA = Golden Arrow, P = Palace, R = Rose, SG = Salmon Gums, Se = Security, Sp = Spinifex, WG = Wendy Gully. * Golden Arrow had too few individuals caught to calculate percentage of rare species.

	C	*D*	*G*	*GA*	*P*	*R*	*SG*	*Se*	*Sp*	*WG*
Total No. of individuals	150	254	241	97	240	279	257	161	250	314
Species richness (S)	21	35	30	17	23	25	26	21	33	25
Individuals										
Agamids	13	10	14	7	4	15	3	20	6	34
Varanids	7	5	7	1	0	2	6	8	2	3
Skinks	26	105	59	19	61	68	38	56	98	89
Geckos	88	105	126	56	156	187	191	71	114	169
Pygopods	3	4	2	0	5	0	0	0	11	5
Elapid snakes	1	13	11	2	8	3	11	3	9	3
Blind snakes	12	12	22	12	6	4	8	3	10	11
Species										
Agamids	2	4	4	2	2	3	2	3	1	4
Varanids	2	2	2	1	0	1	2	1	2	1
Skinks	5	13	9	4	9	8	11	10	13	9
Geckos	7	7	6	7	7	8	5	3	7	6
Pygopods	2	2	2	0	1	0	0	0	5	2
Elapid snakes	1	4	5	2	2	3	4	2	3	1
Blind snakes	2	3	2	1	2	2	2	2	2	2
Percentage of species										
Agamids	9.5	11.4	13.3	11.8	8.7	12.0	7.7	14.3	3.0	16.0
Varanids	9.5	5.7	6.7	5.9	0.0	4.0	7.7	4.8	6.1	4.0
Skinks	23.8	37.1	30.0	23.5	39.1	32.0	42.3	47.6	39.4	36.0
Geckos	33.3	20.0	20.0	41.2	30.4	32.0	19.2	14.3	21.2	24.0
Pygopods	9.5	5.7	6.7	0.0	4.3	0.0	0.0	0.0	15.2	8.0
Elapid snakes	4.8	11.4	16.7	11.8	8.7	12.0	15.4	9.5	9.1	4.0
Blind snakes	9.5	8.6	6.7	5.9	8.7	8.0	7.7	9.5	6.1	8.0
% Species <1%	31.82	41.67	35.48	*	16.67	30.77	48.15	13.64	38.24	42.31
Shannon diversity index (H)	2.40	2.91	2.79	2.44	2.61	2.60	1.75	2.35	2.92	2.41
Evenness (E)	0.61	0.74	0.71	0.62	0.67	0.66	0.45	0.60	0.75	0.62
α Log series diversity	6.64	11.00	9.03	5.97	6.26	6.65	7.22	6.45	10.18	6.39

For the 10 Ora Banda sites, species richness ranged from 17 to 35 (Table 4); geckos were the most common taxonomic group (Fig. 4), followed by skinks. Agamids, elapid snakes and blind snakes were intermediate in commonness and fewer varanids and pygopods were caught. The exceptions were the Davyhurst site that had a similar number of skinks and geckos, and the Gimlet and Golden Arrow sites where blind snakes were slightly more abundant than at other sites (Table 4). H values ranged from 1.7 to 2.9, α log series diversity ranged from 6.3 to 11.0, and evenness ranged from 0.4 to 0.8 for the Ora Banda sites (Table 4). The Morisita-Horn similarity index ranged from 0.04 to 0.87 (Table 5), again demonstrating significant variation in reptile assemblages for closely located sites. Estimated shared species ranged from 9 to 42 species. In many cases the number of shared species was less than the number of species likely to be caught on each of these sites (see Thompson *et al.*, in press).

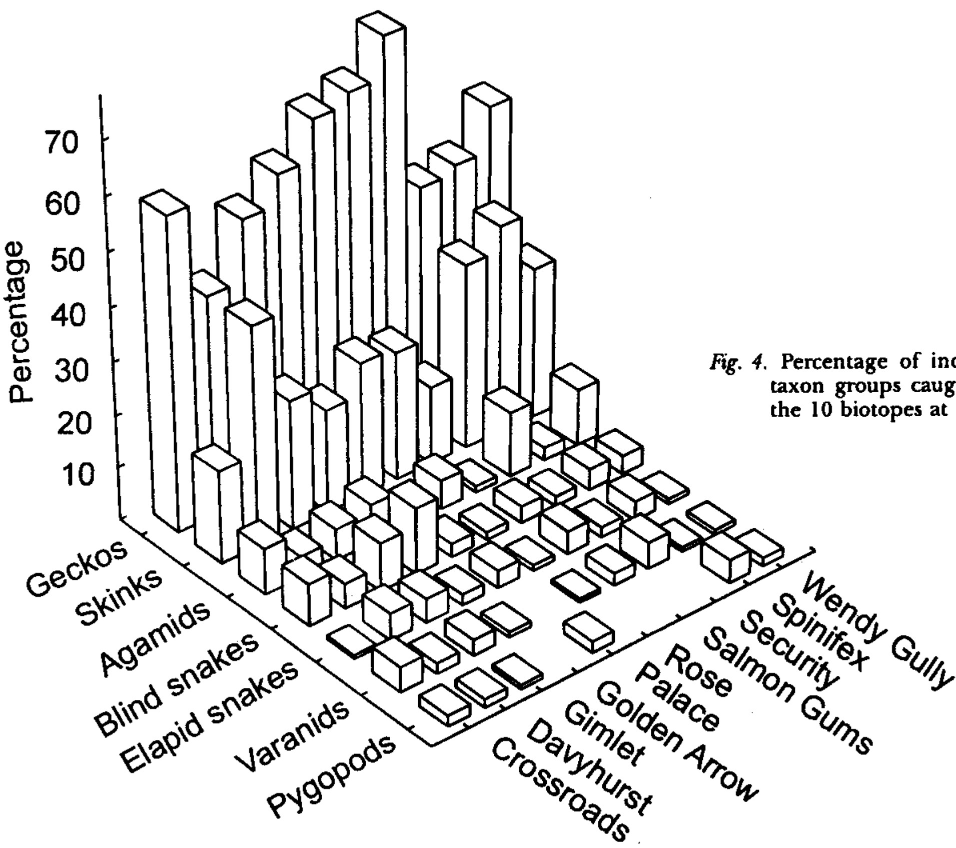

Fig. 4. Percentage of individuals for each of the taxon groups caught in pit-traps at each of the 10 biotopes at Ora Banda.

Table 5. Morisita-Horn similarity index for the 10 Ora Banda sites and an estimate of the shared species among sites in parenthesis. C = Crossroads, D = Davyhurst, G = Gimlet, GA = Golden Arrow, P = Palace, R = Rose, SG = Salmon Gums, Se = Security, Sp = Spinifex, WG = Wendy Gully.

Sites	C	D	G	GA	P	R	SG	Se	Sp	WG
Species richness	22	36	31	18	24	26	27	22	34	26
C		0.69 (42)	0.43 (24)	0.77 (19)	0.68 (15)	0.76 (17)	0.10 (28)	0.76 (17)	0.58 (34)	0.30 (17)
D			0.74 (35)	0.64 (22)	0.83 (22)	0.68 (28)	0.08 (26)	0.69 (18)	0.78 (31)	0.38 (23)
G				0.41 (15)	0.76 (22)	0.63 (24)	0.40 (27)	0.38 (16)	0.68 (29)	0.38 (18)
GA					0.61 (17)	0.57 (19)	0.08 (17)	0.71 (9)	0.62 (20)	0.48 (15)
P						0.87 (19)	0.29 (22)	0.70 (12)	0.70 (20)	0.33 (17)
R							0.35 (25)	0.64 (16)	0.53 (18)	0.26 (12)
SG								0.03 (23)	0.09 (19)	0.04 (17)
Se									0.51 (12)	0.21 (13)
Sp										0.70 (21)

DISCUSSION

Arid and semi-arid Australia has a diverse and abundant assemblage of pit-trappable reptiles. The high species richness values presented generally reflects this high reptile species diversity, and for some sites the large size and diverse habitat of the area surveyed. Pianka (1985) reported typically 4–11 lizard species per site in North America and 12–18 in the Kalahari. It can be seen from data for pit-trapping programmes across heterogenous arid and semi-arid sites in Australia, that reptile species richness was appreciably higher, from 26 to 68. Even for biotopes (e.g., Ora Banda and Bungalbin sites), species richness ranged from 18 to 35. Milewski (1981), Pianka (1986; 1989), and Morton and James (1988) suggested the high lizard species richness in Australian arid areas is a consequence of some lizards usurping the ecological roles of other taxa, their differing abilities to survive and reproduce in arid habitats, the relatively high number of nocturnal species, the unpredictable and irregularly available resources that exclude other taxa and enable lizards to diversify, and the presence of spinifex grasses (*Triodia* and *Plectrachne*) that provide a protective habitat, various micro-habitats, a rich source of insects and a complex fire-succession cycle that provides an ever changing range of habitats.

The Carnarvon Basin recorded the highest number of species as might be expected, because the site was the largest area sampled and included a diverse range of habitats. Nevertheless, the Carnarvon Basin's species richness value of 76 is likely to be an under-estimate of the number of trappable species in the area, since most of the species accumulation curves for the 13 sub-sites surveyed had not plateaued (McKenzie *et al.* 2000). Other sites with high species richness were Lake Eyre (another large site with a range of habitats), and Ora Banda (a smaller area but with a diverse range of habitats). Redsands was a comparatively small (≈1 km^2) heterogenous site (sand ridge crests and slopes, swales, etc.), but had a species richness of 68, which was appreciably more than that of other red sand ridged areas that were predominantly vegetated with spinifex. The reason for this is unknown, but may reflect the intensive sampling effort and the period over which the data were collected (1989–1998), as both sampling effort and period of sampling influence species richness (Preston 1960; Rosenzweig 1995; Thompson *et al.*, in press). James (1989) collected data from in excess of 50 000 pit-trap days at the Ewaninga site (which is approximately twice the number of pit-trap days used at Redsands) in a red sand ridged area that was vegetated with spinifex and recorded 45 species, suggesting that the intensity of trapping was not the only factor affecting species richness at Redsands. L area in the Great Victoria Desert (which does not have the high sand ridges) was a less diverse habitat than Redsands and had a lower total number of individuals caught, both of which probably contribute to its lower species richness. The number of individuals caught at the Central Wheatbelt sites was high (>7 000), but only 42 species were caught. The Central Wheatbelt site included one relatively large nature reserve, and eight smaller sites that were all surrounded by agricultural or disturbed lands. For many of these sites, once a species had gone locally extinct, there would be little opportunity for recruitment from adjacent areas, which may account for some loss of species richness.

The low species richness for Bold Park was probably because there are generally fewer reptile species in mesic environments, and as a result of human impact and fires (How 1998), since this area has no capacity to recruit species once they have become locally extinct. This site has few dragons and geckos, taxa that are relatively abundant at other sites. Roxby Downs has relatively low species richness, and this is most probably a result of the small area sampled (1 ha). Uluru, Simpson and Tanami (A) desert sites all had comparatively low total catch numbers, were relatively homogenous study sites, and were relatively small study sites, all of which probably contributed to their low species richness. The affect of trapping effort can be illustrated in the two Tanami desert surveys. The Morton *et al.* (1988) survey caught a total of 898 individuals and 32 species, whereas the Hobbs *et al.* (1994) survey caught 5 502 individuals and recorded 40 species (also see Thompson *et al.*, in press).

Landscape scale arid and semi-arid sites typically have 3–8 pit-trappable agamid species, 1–5 varanid species, 10–24 skink species, 6–12 gecko species, 2–6 pygopod species, 2–9 elapid snakes species and 1–2 blind snake species, but some sites fall outside these ranges. As expected, the number of species in all taxonomic groups was lower in the more homogenous biotopes surveyed, as the sampled areas were smaller (Borda-de-Agua *et al.* 2002).

For the heterogenous sites, the most common specimens caught were skinks, followed by geckos then agamids. There are, however, some exceptions to this generalisation. The most obvious of these was the reversal of the skink-gecko abundance proportions for the Ora Banda site. Ora Banda's high proportion of geckos possibly relates to the woodland-type vegetation common at this site. Two hundred and thirty-two of the 2 093 individuals caught were *Diplodactylus maini*, most of which were pit-trapped in the eucalypt woodland areas. The Simpson Desert site had a low number of geckos, but a relatively high number of gecko species (8). This might have been an artefact of the trapping period as activity patterns of geckos are influenced by ambient environmental conditions (How and Kitchener 1983; Read and Moseby 2001). The relatively high number of varanids in the Simpson Desert was the result of capturing *Varanus brevicauda*, *V. eremius* and *V. gouldii*. Most inland arid Australian areas vegetated with *Triodia* spp. have the potential to catch *V. eremius*, *V. brevicauda*, *V. gouldii*, *V. giganteus*, *V. tristis* and *V. caudolineatus* or *V. gilleni*. Interestingly, no *V. eremius* were caught at Ewaninga, although this is within their geographical distribution (Cogger 1992) and they are generally quite abundant in the red, sandy ridged areas of inland Australia. The smaller varanid species are generally easily pit-trapped, but mostly only juveniles of larger species are caught in pit-traps. Blind snakes constitute between 4–5% of the total number of individuals caught at Ewaninga and Ora Banda, although most sites only have one or two species present. Interestingly, no blind snakes have been caught on the yellow sandplains at Bungalbin, although it is within the geographical distribution of a number of species (Storr *et al.* 1986). The lack of captures does not necessarily mean blind snakes are not present; however, given the trapping effort of 41 000 pit-trap days, the probability of their subsequent capture is low.

Rare species — An obvious feature of all heterogenous sites is the low and variable evenness scores (0.32–0.68) and the high proportion of rarely caught species (26–57%); the high proportion of species with a low capture rate is a primary determinant of low evenness values. Apparent rareness can be a result of: a) the low propensity of a species to be caught in pit-traps because of its size (e.g., *Varanus giganteus*); b) the nature of the preferred habitat (e.g., the arboreal and relatively sedentary *Caimanops amphiboluroides*); c) a small activity range not including a pit-trap; and d) fossoriality or confinement to a burrow complex (e.g., *Egernia striata*). Alternatively, species may be easily pit-trapped, but are indeed "rare". Such rareness can be defined as species that are: a) broad ranging but generally sparsely distributed; b) locally dense but with a very restricted range; and c) locally sparse with very restricted range. In a pit-trapping programme, two additional categories of rareness can be identified, namely: a) when the sampling area is on the boundary of the distribution of a common species and only an occasional individual is caught; and b) when "transients" pass through a surveyed area that is not typical of their habitat. These transients can recolonize new habitats, or are "lost". Rarity remains a major challenge for ecologists to explain (Main 1982).

How do rare species differ from those that are simply difficult to pit-trap? Rosenzweig and Lomolino (1997) suggested that rare species are those that are intolerant (e.g., without the ability to use most habitats and to co-exist with other taxa), large bodied, occupy an extreme niche, occupy a narrow niche or depend on a resource that is becoming scarce, or are vulnerable to new competition or exploitation. Human disturbance or introduction of exotic species has often been cited as a primary reasons for rarity leading to extinction. Difficult to pit-trap species are those that can easily escape from pit-traps (e.g., *Ctenophorus cristatus*), are too big to fall into pit-traps (e.g., *Chlamydosaurus kingii*), or those that have small activity areas (e.g., *Ctenophorus nuchalis*). Given that the propensity for reptile species to be pit-trapped varies enormously, pit-trap data cannot be used as an indication of actual reptile community structure. However, data collected during systematic pit-trapping programmes can be used to compare the pit-trappable assemblage diversity, evenness, biodiversity and ecosystem function among sites, presuming the trap-ability of a species remains unchanged in different habitats.

Why are some species rare and not just difficult to pit-trap? Rareness can result from species being poorly adapted to the environment, adapted to a limited range of environmental conditions, isolated by environmental or geophysical changes to an area, having low dispersal ability or having a narrow niche (Main 1982; Gaston and Kunin 1997). The Environmental Protection Authority (2002) argues that terrestrial fauna survey data should be placed in the context of biodiversity and ecosystem functional value. If species richness is considered important as one component of diversity, then a considerable number of reptile species that add to the biodiversity of an area are rare, or at least are rarely caught in pit-traps. Rare species, then, have significant implications for the trapping effort in terrestrial fauna surveys, as discussed below.

Rare species have drawn considerable attention and financial research support from government agencies. The Environmental Protection Authority (2002) indicates that terrestrial survey fauna data should be interpreted such that biodiversity is considered at the genetic, species and ecosystem level. From a species point of view when governments are considering a development proposal, areas of "special interest" can be those where rare species are relatively abundant, or are habitats that contain rare species. From an ecosystem or biodiversity point of view, areas of high species diversity or unusual assemblage (e.g., variations from the norm in S, H or E) could be deemed to be of significant biological importance and worthy of preservation. From a genetic perspective, individuals from species that are isolated from their "main" geographical distributions due to environmental or geophysical changes are probably of biological importance. If species occupy a narrow niche outside of their normal distribution, then they maybe deemed "rare" in the analysis of a terrestrial pit-trapping survey results of large and diverse habitats, and therefore deserve attention.

Biotope comparison

Proponents, whose activities create disturbance (e.g., mining companies), or their consultants, seldom undertake a comprehensive terrestrial fauna survey of an area during the preparation of an environmental impact assessment. Most often a small-scale survey (less than 1 000 pit-trap days of data) is undertaken and most of the vertebrate fauna information for an environmental impact assessment comes from a "species list" that is compiled from landscape and regional scale biological surveys previously undertaken by government agencies and from searches of museum databases (see Read 1994 for an example). How accurate and useful are these data in determining the reptile fauna for a particular biotope and how easy is it to miss potentially "important" species? Landscape scale survey data or museum collection data would be useful if reptile diversity was reasonably evenly distributed across the landscape, but is it?

Similarity index values for the 12 sites at Bungalbin and 10 sites at Ora Banda indicate that reptile assemblages (Tables 3 and 5) within a relatively small area differ appreciably. Although the α log series diversity index statistic varies among sites, a comparison of observed values in each of the $\log_2$ classes for each of the sites indicates that values do not differ significantly among sites (Bungalbin χ^2 = 60, df = 66; p = 0.69; Ora Banda χ^2 = 59, df = 63, p = 0.64) and an estimate of shared species among sites is close to the number of species being caught at each site (Tables 3 and 5). Therefore, with additional trapping effort, it could be expected that the species inventory for each site might not vary much among sites. However, the structure of the reptile assemblage is likely to be very different (Figs 3 and 4). For example, compared with the other sites at Bungalbin, L site the number of geckos is comparatively high, and the number of agamids is low, in contrast, the adjacent M site (Fig. 3) which has a comparatively high number of skinks and low number of agamids, yet these sites are less than 400 m apart. The choice of the overall study site at Bungalbin was based on similarity of habitats. Sites L and M have similar soils and vegetation, yet there is a noticeable difference in reptile assemblages. Vegetation differences among sites at Ora Banda are much more marked (Fig. 4), with Davyhurst, Security and Spinifex sites having a comparatively low number of geckos and a high number of skinks when compared with other sites. The number of agamid species caught at Security and Wendy Gully was comparatively higher than elsewhere, and blind snakes were more abundant at Golden Arrow, Gimlet and Crossroads than the other sites (Fig. 4). These data indicate considerable variation in reptile assemblages for closely located sites both with and without similar soils and vegetation.

The number of species with individual capture rates less than 1% is generally between 20 and 45% of the total number of species for each of the biotopes, which is similar to the pattern for the heterogeneous sites. This high proportion of rare species is the primary reason for the relatively low evenness index values for the sites (Tables 2 and 4).

Landscape scale terrestrial fauna surveys of the type typically carried out by government agencies (e.g., Storr and Harold 1978, 1980, 1984, 1985; Storr and Hanlon 1980; Storr *et al.* 1983; Dell *et al.* 1985; McKenzie *et al.* 1989, 2000; McKenzie and Hall 1992) and searches of museum collection databases are unlikely to provide the "fine grain" level of detail to understand reptile fauna assemblages at any particular site. An example to demonstrate this is the regional survey undertaken jointly by the now Department of the Environment, Department of Conservation and Land Management and Western Australian Museum (WAM) of the Goldfields region of Western Australia in the late 1970s–early 1980s with the specific purpose of documenting the fauna and flora of the area. Based on an extensive survey of the Black Flag and Kurnalpi survey areas, McKenzie *et al.* (1992) reported 44 species of reptiles in the area (Table 6). A subsequent search of the WAM collection database added another 18 species that could occur in this area (Table 6). These are the two primary sources of information on species (and relative abundances) for the Ora Banda area that are available to mining companies and consultants. Although our terrestrial fauna survey of the Ora Banda area was not designed to comprehensively survey the area, but to survey specific habitats, we found 16 species not caught by the government survey group (Table 6). When the government agencies survey list was supplemented by those species "thought likely" to be found in the area, based on a search of the WAM collection, we recorded eight species not reported for the area. Two points can be made as a consequence of these data, namely that; a) the survey protocol and trapping effort of the government agencies was inadequate to provide a comprehensive species list for a specific site in the area; and b) even though government agencies had undertaken a "comprehensive" biological survey for the region, these data when added to the information contained in the WAM collection were still inadequate to prepare a comprehensive environmental impact assessment species list for a specific site within the landscape of Ora Banda. Given the incomplete species list, relative abundance and diversity index scores reported in an environmental impact assessment for the area are not likely to be similar to ours, which are based on a more extensive survey. To "comprehensively" survey this region to the level that the data can be used to a compile species list for any particular site requires a much greater trapping effort and expense than was employed by these government agencies (see Thompson *et al.*, in press). In addition, pit-trapping does not catch all the species in an area (see discussion above). These findings are similar to those reported by Read (1994). Read (1994) reported a pilot fauna reconnaissance survey of the Olympic Dam site recorded 10 species, a subsequent survey (410 hr diurnal searching, 206 hr nocturnal searching and 200+

Table 6. Species caught in the vicinity of Ora Banda during a government sponsored survey and additional species suggested to occur in the area after a search of the Western Australian Museum collection compared with species we caught in a pit-trapping programme for part of the Ora Banda landscape.

Species	Gov't Survey[1]	WAM Collection[2]	OB pit-trapped[3]	OB seen or caught by other means[4]
Caimanops amphiboluroides	*			*
Ctenophorus cristatus	*		*	
Ctenophorus fordi	*			
Ctenophorus reticulatus	*		*	
Ctenophorus salinarum	*			
Ctenophorus scutulatus	*		*	
Moloch horridus	*		*	
Pogona minor	*		*	
Tympanocryptis cephala		*	*	
Varanus caudolineatus	*		*	
Varanus gouldii	*		*	
Varanus tristis		*	*	
Cryptoblepharus plagiocephalus	*		*	
Ctenotus atlas	*		*	
Ctenotus leonhardii	*			
Ctenotus pantherinus		*		
Ctenotus schomburgkii	*		*	
Ctenotus uber	*		*	
Cyclodomorphus melanops elongatus	*		*	
Egernia depressa	*		*	
Egernia formosa	*		*	
Egernia inornata	*		*	
Egernia striata			*	
Eremiascincus richardsonii		*	*	
Hemiergis initialis			*	
Lerista muelleri	*		*	
Lerista picturata	*		*	
Menetia greyii	*		*	
Morethia butleri	*		*	
Morethia adelaidensis	*			
Tiliqua occipitalis	*		*	
Tiliqua rugosa	*		*	
Delma australis	*		*	
Delma butleri			*	
Delma fraseri			*	
Delma nasuta	*			
Lialis burtonis	*		*	
Pygopus lepidopodus		*	*	
Pygopus nigriceps		*		
Diplodactylus assimilis			*	
Diplodactylus conspicillatus		*		
Diplodactylus damaeus		*		
Diplodactylus elderi	*			
Diplodactylus granariensis	*		*	
Diplodactylus intermedius		*		
Diplodactylus maini	*		*	
Diplodactylus pulcher	*		*	
Gehyra purpurascens			*	
Gehyra variegata	*		*	
Heteronotia binoei	*		*	
Nephrurus vertebralis	*			
Nephrurus laevis				*
Oedura reticulata	*		*	
Rhynchoedura ornata	*		*	
Underwoodisarus milii	*		*	
Simoselaps bertholdi	*		*	
Neelaps bimaculatus		*		
Brachyurophis semifasciata			*	
Suta fasciata		*	*	
Demansia psammophis			*	
Pseudechis australis		*		*
Pseudonaja modesta	*		*	
Pseudonaja nuchalis	*			*
Parasuta gouldii	*			
Parasuta monachus	*		*	
Acanthopis pyrrhus		*		
Ramphotyphlops australis		*	*	
Ramphotyphlops bituberculatus		*	*	
Ramphotyphlops hamatus		*	*	
Ramphotyphlops waitii		*		
Morelia spilota		*		*

[1]Caught in a fauna survey of the Black Flag and Kurnalpi area (McKenzie and Hall 1992); [2]Additional species likely to occur in the area based on museum records (McKenzie and Hall 1992); [3]Species caught in our pit-trapping programme for a small section of the Ora Banda region; [4]Additional species seen or caught in the area but not pit-trapped.

pit-fall trap days) increased the known number of species to 34. Of the 24 species recorded in the second survey, all but seven (six snakes and *Tiliqua occipitalis*) were thought to occur in the area based on a desktop and field pilot survey. After considerable additional fauna monitoring, only seven of the 19 species thought to be in the area were known to be present. Read (1994) concluded the brief fauna survey that was based largely on a literature review was not an adequate substitute for detailed investigation of poorly-studied sites, a view that we would concur with. Read (1994) went on to indicate that long-term surveys, conducted over a range of climatic extremes, are still essential to determine the status and population patterns of arid zone reptiles, again a conclusion that we support (see Moseby and Read 2001; Thompson *et al.* in press).

Where there are no systematically collected survey data for an area (i.e., most of the Australian continent), and mining companies or consultants use only data contained in museum collection databases, then the potential for omission of species and misinterpretation of vertebrate community structure and ecosystem function is high. Ponder *et al.* (2001) reported the following shortcomings of museum collection databases: ad hoc nature of collections; presence-only data; biased sampling; and large gaps in time and space. All of these contribute to the potential errors in the interpretation of the data when assessing S, H and E of an assemblage for a site.

Consequences of these findings for future environmental impact assessment terrestrial fauna surveys — For Redsands, approximately 25.5 individuals were caught for every 100 pit-trap days, for Ora Banda there was approximately 9.5 individuals were caught per 100 pit-trap days, for Bungalbin approximately 7 individuals were caught per 100 pit-trap days, and for the central wheatbelt 11.5 individuals were caught per 100 pit-trap days (when only the warmer months were sampled). Thompson *et al.* (in press) suggested that approximately 12 200 and 1 370 individual reptiles would need to be caught at Bungalbin and Ora Banda respectively to record 95% of the species in the area. A much higher trapping effort would be required to record the complete inventory of species. If pit-trappable reptile assemblages are to be adequately described, and to include rare species, then the survey effort must be appreciably higher than what is currently being undertaken. In a survey of 15 recent environmental impact assessment reports in the Goldfields region of Western Australia, the mean number of pit-trap days per season was 69, and the combined number for all seasons was 81 at the biotope scale, and 571 at the landscape scale per season and 693 pit-trap days for combined seasons (unpubl. data, J. Fraser and G. Thompson). Clearly, this level of pit-trapping is inadequate to describe reptile assemblages and would, at best, only indicate common species. Information on common species can already be inferred from the literature (e.g., Dell *et al.* 1985, 1988; McKenzie and Hall 1992) or from a search of museum collection databases. One of the purposes of a pit-trapping programme is to draw to the proponent's attention those species not thought to be in the area (based on a search of the literature and museum records) or species that are rare or are of special interest.

If governments and environmental protection authorities are concerned about the potential impact of proposed disturbances of mining or other developments on rare or range restricted species, then they need to demand a much higher level of field survey effort to adequately describe reptile assemblages at both the landscape and biotope scales.

The Western Australian Environmental Protection Authority (Environmental Protection Authority 2002) indicates that where the scale and nature of the impact are "low" and "moderate" in the Great Sandy Desert, Gibson Desert, Great Victoria Desert, Little Sandy Desert, Central and Tanami Deserts, only a desktop study and a reconnaissance survey are necessary. These are generally large areas for which there are limited data for specific sites (see Thomson and Hosmer 1963; Pianka 1969, 1972, 1986, 1996; Burbidge *et al.* 1976; McKenzie and Burbidge 1979; Burbidge 1983; Gibson 1986; Gibson and Wurst 1994; Read 1998). For areas that have been "extensively" surveyed by government agencies (e.g., Avon Wheatbelt, Coolgardie, Geraldton Sandplains, and Carnarvon Interim Biogeographic Regions) and where the potential impact of the disturbance is considered to be either "moderate" or "high", then a desktop study, a reconnaissance survey and a comprehensive flora and fauna survey are required. Based on our assessment of available data held by government agencies such as the Department of Conservation and Land Management and the WAM, comprehensive fauna surveys should be required at all sites unless the proponents can demonstrate that prior surveys for the area provide a near complete inventory of species in the area. Thompson *et al.* (in press), using species accumulation curves, provided guidelines on how to assess the amount of pit-trapping effort that is necessary to detect various proportions of the total trappable species for an area.

ACKNOWLEDGEMENTS

We thank Chris Dickman and volunteers for assisting in the pit-trapping at Bungalbin, the large number of volunteers that assisted at Ora

Banda. OMG Cawse Nickel Operations are thanked for financially supporting the research at Ora Banda and Placer Dome Asia Pacific's Paddington Gold operations for providing logistical support. ERP thanks the National Geographic Society and the Denton A. Cooley Centennial Professorship in Zoology at the University of Texas in Austin, both of which helped fund his research at Redsands and the GVD L area. Reptiles were caught with the approval of the Department of Conservation and Land Management.

REFERENCES

Borda-de-Agua, L., Hubbell, S. P. and McAllister, M., 2002. Species-area curves, diversity indices, and species abundance distributions: a multifractal analysis. *Am. Nat.* **159:** 138–55.

Burbidge, A. A., 1983. Part V Amphibians and Reptiles. Pp. 109–20 *in* Wildlife of the Great Sandy Desert, Western Australia (Vol. 12) ed by A. A. Burbidge and N. L. McKenzie. Western Australian Wildlife Research Centre, Department of Fisheries and Wildlife, Perth.

Burbidge, A. A., McKenzie, N. L., Chapman, A. and Lambert, P. M., 1976. The wildlife of some existing and proposed reserves in the Great Victoria and Gibson Deserts, Western Australia. *Wildl. Res. Bull. West. Aust.* **5:** 1–16.

Chao, A., Hwang, W.-H., Chen, Y.-C. and Kuo, C.-Y., 2000. Estimating the number of shared species in two communities. *Statistica Sinica* **10:** 227–46.

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

Dell, J., How, R. A., Milewski, A. V. and Keighery, G. J., 1988. The biological survey of the eastern goldfields of Western Australia Part 5, Edjudina - Menzies study area. *Rec. West. Aust. Mus. Suppl.* **31**, pt **5:** 38–69.

Dell, J., How, R. A., Newbey, K. R. and Hnatiuk, R. J., 1985. The biological survey of the eastern goldfields of Western Australia. *Rec. West. Aust. Mus. Suppl.* **23**, pt **3:** 1–168.

Downey, F. J. and Dickman, C. R., 1993. Macro- and microhabitat relationships among lizards of sandridge desert in central Australia. Pp. 133–38 *in* Herpetology in Australia: A Diverse Discipline ed by D. Lunney and D. Ayers. Transactions of the Royal Society of New South Wales, Sydney.

Environmental Protection Authority, 2000. General Requirements for Terrestrial Biological Surveys for Environmental Impact Assessment in Western Australia. Position Statement No. 3. Environmental Protection Authority, Perth.

Environmental Protection Authority, 2002. Terrestrial Biological Surveys as an Element of Biodiversity Protection. Environmental Protection Authority, Perth.

Gaston, K. J. and Kunin, W. E., 1997. Rare-common differences: an overview. Pp. 12–29 *in* The Biology of Rarity ed by W. E. Kunin and K. J. Gaston. Chapman and Hill, London.

Gibson, D. F., 1986. A biological survey of the Tanami desert in the Northern Territory. Conservation Commission of the Northern Territory, Alice Springs.

Gibson, D. F. and Wurst, P. D., 1994. Reptile Survey of the Wakaya Desert, Northern Territory. Conservation Commission of the Northern Territory, Alice Springs.

Hayek, L. A. and Buzas, M. A., 1997. Surveying Natural Populations. Columbia University Press, New York.

Hobbs, T. J., Morton, S. R., Masters, P. and Jones, K. R., 1994. Influence of pit-trap design on sampling of reptiles in arid spinifex grasslands. *Wildl. Res.* **21:** 483–90.

How, R. A., 1998. Long-term sampling of a herpetofaunal assemblage on a isolated urban bushland remnant, Bold Park, Perth. *J. Roy. Soc. West. Aust.* **81:** 143–48.

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.

James, C. D., 1989. Comparative Ecology of Sympatric Scincid Lizards (*Ctenotus*) in Spinifex Grasslands of central Australia. Unpublished PhD, University of Sydney, Sydney.

Magnussen, S. and Boyle, T. J. B., 1995. Estimating sample size for inference about the Shannon-Weaver and the Simpson indices of species diversity. *Forest Ecol. Man.* **78:** 71–84.

Magurran, A. E., 1988. Ecological Diversity and Its Measurement. Princeton University Press, Princeton, New Jersey.

Main, A. R., 1982. Rare species: precious or dross? Pp. 163–74 *in* Species at Risk: Research in Australia ed by R. H. Groves and W. D. L. Ride. Australian Academy of Science, Canberra.

Masters, P., 1996. The effects of fire-driven succession on reptiles in spinifex grasslands at Uluru National Park, Northern Territory. *Wildl. Res.* **23:** 39–48.

McKenzie, N. L. and Burbidge, A. P., 1979. The wildlife of some existing and proposed native reserves in the Gibson, Little Sandy and Great Victoria Deserts, Western Australia. *Wildl. Res. Bull. West. Aust.* **8:** 1–36.

McKenzie, N. L. and Hall, N. J., 1992. The biological survey of the eastern goldfields of Western Australia, pt 8 Kurnalpi-Kalgoorlie study area. *Rec. West. Aust. Mus. Suppl.* **41:** 37–64.

McKenzie, N. L., Rolfe, J. K. and Carter, D., 1989. Reptiles. Pp. 179–210 *in* A Biological Survey of the Nullabor Region of South and Western Australia in 1984 ed by N. L. McKenzie and A. C. Robinson. Department of Conservation and Land Management, Perth.

McKenzie, N. L., Robinson, A. C. and Belbin, L., 1991. Biogeographic survey of the Nullarbor District, Australia. Pp. 109–26 *in* Nature Conservation: Cost Effective Biological Surveys and Data Analysis ed by C. R. Margules and M. P. Austin. CSIRO, Canberra.

McKenzie, N. L., Rolfe, J. K. and Youngson, W. K., 1992. IV Vertebrate fauna. *Rec. West. Aust. Mus. Suppl.* **41:** 37–64.

McKenzie, N. L., Keighery, G. J., Gibson, N. and Rolfe, J. K., 2000. Patterns in biodiversity of terrestrial environments in the southern Carnarvon Basin, Western Australia. *Rec. West. Aust. Mus.* **61:** 511–46.

McKenzie, N. L., Rolfe, J. K., Aplin, K. P., Cowan, M. A. and Smith, L. A., 2000. Herpetofauna of the southern Carnarvon Basin, Western Australia. *Rec. West. Aust. Mus. Suppl.* **61:** 335–60.

Milewski, A. V., 1981. A comparison of reptile communities in relation to soil fertility in the mediterranean and adjacent arid parts of Australia and southern Africa. *J. Biogeog.* **8:** 493–503.

Morton, S. R. and James, C. D., 1988. The diversity and abundance of lizards in arid Australia: a new hypothesis. *Am. Nat.* **132:** 237–56.

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. 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.

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

Pianka, E. R., 1972. Zoogeography and speciation of the Australian desert lizards: An ecological perspective. *Copeia* **1972**: 127–45.

Pianka, E. R., 1985. Some intercontinental comparisons of desert lizards. *Nat. Geog. Res.* **1**: 490–504.

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., 1989. Desert lizard diversity: Additional comments and some data. *Am. Nat.* **134**: 344–64.

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.

Ponder, W. F., Carter, G. A., Flemons, P. and Chapman, R. R., 2001. Evaluation of museum collection data for use in biodiversity assessment. *Conserv. Biol.* **15**: 648–57.

Preston, F. W., 1960. Time and space and the variation of species. *Ecology* **29**: 254–83.

Read, J., 1998. Vertebrate fauna of the Nifty mine site, Great Sandy Desert, with comments on the Impacts of mining and rehabilitation. *West. Aust. Nat.* **22**: 1–21.

Read, J. L., 1994. A retrospective view of the quality of the fauna component of the Olympic Dam project Environmental Impact Statement. *J. Environ. Man.* **41**: 167–85.

Read, J. L., 1995. Subhabitat variability: A key to the high reptile diversity in chenopod shrublands. *Aust. J. Ecol.* **20**: 494–501.

Read, J. L. and Owens, H. M., 1999. Reptiles and amphibians of the Lake Eyre south region. Pp. 111–214 *in* Lake Eyre south monographs series (Vol. 1) ed by W. J. H. Slaytor. Royal Geographical Society of South Australia, Adelaide.

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.

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. Suppl.* **61**: 361–70.

Rosenzweig, M. L., 1995. Species Diversity in Space and Time. Cambridge University Press, Cambridge.

Rosenzweig, M. L. and Lomolino, M. V., 1997. Who gets the short bits of the broken stick? Pp. 63–90 *in* The Biology of Rarity ed by W. E. Kunin and K. J. Gaston. Chapman and Hall, London.

Shephard, M., 1995. The Great Victoria Desert. Reed, Sydney.

Smith, G. T., Leone, J. and Dickman, C. R., 1997. Small terrestrial vertebrate communities in remnant vegetation in the central wheatbelt of Western Australia. *West. Aust. Nat.* **21**: 235–49.

Species Diversity and Richness II V2.6, 2002. Pisces Conservation. Lymington, England.

Storr, G. M. and Hanlon, T. M. S., 1980. Herpetofauna of the Exmouth region, Western Australia. *Rec. West. Aust. Mus.* **8**: 423–39.

Storr, G. M. and Harold, G., 1978. Herpetofauna of the Shark Bay region, Western Australia. *Rec. West. Aust. Mus.* **6**: 449–67.

Storr, G. M. and Harold, G., 1980. Herpetofauna of the Zuytdorp coast and hinterland, Western Australia. *Rec. West. Aust. Mus.* **8**: 359–75.

Storr, G. M. and Harold, G., 1984. Herpetofauna of the Lake MacLeod region, Western Australia. *Rec. West. Aust. Mus.* **11**: 173–89.

Storr, G. M. and Harold, G., 1985. Herpetofauna of the Onslow region, Western Australia. *Rec. West. Aust. Mus.* **12**: 277–91.

Storr, G. M., Hanlon, T. M. S. and Dunlop, J. N., 1983. Herpetofauna of the Geraldton region, Western Australia. *Rec. West. Aust. Mus.* **10**: 215–34.

Storr, G. M., Smith, L. A. and Johnstone, R. E., 1986. Snakes of Western Australia. Western Australian Museum, Perth.

Thompson, G. G. and Withers, P. C. (in press). The effect of species richness and relative abundance on the shape of the species accumulation curve. *Austral. Ecol.*

Thompson, G. G., Withers, P. C., Pianka, E. R. and Thompson, S. A. (in press). Assessing biodiversity with species accumulation curves; inventories of small reptiles by pit-trapping in Western Australia. *Austral. Ecol.*

Thomson, D. F. and Hosmer, W., 1963. A preliminary account of the herpetology of the Great Sandy Desert of central Western Australia. Reptiles and amphibians of the Bindibu expedition. *Proc. Roy. Soc. Vic.* **77**: 217–37.