Determining adequate trapping effort and species richness using species accumulation curves for environmental impact assessments

GRAHAM G. THOMPSON,[1]* SCOTT A. THOMPSON,[2] PHILIP C. WITHERS[3] AND JASON FRASER[3]

[1]*Centre for Ecosystem Management, Edith Cowan University, 100 Joondalup Drive, Joondalup, WA 6027, Australia (Email: g.thompson@ecu.edu.au),* [2]*ATA Environmental, Dilhorn House, Perth, and* [3]*Zoology, School of Animal Biology, University of Western Australia, Crawley, Western Australia, Australia*

Abstract Environmental impact assessments (EIA) require that the proponent indicates the potential impact that a development will have on the biodiversity of the area. As part of this assessment it is normal practice to inventory the vertebrate species in the area. We show here how species accumulation curves can be used as a tool by environmental consultants to indicate the adequacy of their trapping effort and predict species richness for a disturbance site. The shape of a species accumulation curve is influenced by the number of species in an assemblage and the proportional number of singletons (rarely caught species) in the survey sample. We provide guidelines for the number of individuals that need to be caught in a trapping program to achieve 80% and 90% of the species in a habitat, and we indicate how this number can be adjusted to accommodate variations in relative species abundance.

Key words: EIA, species accumulation curve, species richness, terrestrial fauna survey, trapping effort.

INTRODUCTION

Environmental impact assessments (EIA) are undertaken to describe the potential impact that a disturbance will have on the natural environment. Often as part of an EIA a terrestrial fauna survey is usually undertaken to assess how the development will impact on the fauna. For example, the Western Australian (WA) Environmental Protection Authority (EPA) has indicated that it 'expects proponents to ensure that terrestrial biological surveys provide sufficient information to address biodiversity conservation and ecological function values within the context of the type of proposal being considered . . . Best practice assessment now requires that biodiversity be considered to have two key aspects, namely; (i) its biodiversity value at the genetic, species, and ecosystem levels; and (ii) its ecological functional value at the ecosystem level' (Environmental Protection Authority (EPA) 2002). To achieve this outcome terrestrial fauna surveys must provide an inventory of most of the vertebrate species found at the site.

Species accumulation curves are one of a number of statistical tools available to estimate species richness (McKenzie *et al.* 2000a,b; How & Cooper 2002; Thompson *et al.* 2003; How & Dell 2004). They are regularly used to assess the adequacy of survey effort to inventory species at a site (Soberón & Llorente 1993; Colwell & Coddington 1994; Hayek & Buzas 1997; Moreno & Halffter 2000). Nevertheless, environmental consultants typically do not use any of these tools when describing terrestrial faunal assemblages. Where species accumulation curves are reported, usually only plots of the actual data are presented, and very few reports give a smoothed averaged species accumulation curve or its regression function to predict species richness (How *et al.* 1988; McKenzie *et al.* 2000a,b).

Species accumulation curves can be used to determine the trapping effort necessary to catch a nominated percentage of species if the relationship between the trapping effort and number of species caught is known (Soberón & Llorente 1993). These data can then be used to estimate the cost of field work more rigorously.

Aims and objectives

The aim of this paper is to explore the usefulness of species accumulation curves as a practical tool that environmental consultants might use to: (i) indicate

*Corresponding author.
Accepted for publication October 2006.

the adequacy of their trapping effort; and (ii) predict species richness for a habitat.

The shape of a species accumulation curve is altered by structural differences in faunal assemblages (Thompson & Withers 2003), and by catch rates and species richness. To address our two aims, it is necessary to understand how temporal and cumulative sampling effects influence the slope of species accumulation curves. We assessed how the shape of species accumulation curves is altered when sampling:

A The same habitat with the same trapping protocol but in different seasons
B The same habitat with the same trapping protocol in the same season but in different years
C The same habitat with the same trapping protocol but cumulatively summing the data for successive surveys

We also investigate:

D The trapping effort required to capture an estimated 80% and 90% of the species in a single homogenous habitat
E The trapping effort required to capture an estimated 80% and 90% of the species in a heterogeneous habitat

We have selected 80% and 90% because it is generally considered unreasonable to inventory all species because of the effort required (Moreno & Halffter 2000), and 90% provides a good estimate of the total faunal assemblage. In some circumstances it is not practical to catch sufficient individuals to record 90% of the estimated number of species in a habitat using the asymptote of the species accumulation curve, so we have also included 80%.

A species accumulation curve can be derived from the number of species caught, the relative abundance of each species and the number of trapping periods (Thompson & Thompson 2007). In this analysis, we use data sets with these parameters from the literature, as few (if any) provide the number of individuals caught per species per trapping period.

METHODS

To address our objectives we selected 11 fauna surveys, of which three are from the literature and eight are our own.

Surveys and site descriptions

Reptile assemblage: Abydos Plain, Pilbara, WA (How & Dell 2004)

We used the data for lizards and snakes (but not frogs) for three of eight habitats sampled between March 1988 and November 1990 using pitfall and Elliott traps on the Abydos Plains in the Pilbara of WA (21°36′S, 118°59′E). The sampling effort for each survey and in each habitat differed and totalled 2484 pit trap nights and 8131 Elliott trap nights accumulated over nine surveys. We presumed the majority of reptiles were caught in pitfall traps, and calculated species accumulations curves for reptiles based on 61 days of pit trap sampling. These data were used to address objective D.

Reptile assemblage: Roxby Downs, South Australia (Read 1995)

This 1-ha heterogenous chenopod habitat (30°29′S, 136°53′E) had 401 pit traps placed at 5 m intervals and was sampled for 10 discrete 24-h periods for each season from summer 1990/1991 until winter 1993, providing a total of 41 100 trap days of data. Only the reptile data were used (i.e. frogs were excluded) in the analysis. These data were used to assess objective E.

Reptile and mammal assemblage: Cataby, WA (our data)

The Cataby site was on the northern Swan Coastal Plain, WA (20°39′S, 115°27′E). Two relatively homogenous habitat types (Alpha and Beta) were surveyed on two occasions (November 2003 and February 2004). Each site contained 176 pit traps and 88 funnel traps. The trapping effort was 3168 trap nights in November and in February for both the Alpha and Beta sites. We used all reptiles and mammals trapped in the analysis. These data were used to assess objectives A and D.

Reptile and mammal assemblage: Cervantes, WA (our data)

The Cervantes site (30°30′S, 115°04′E) was on the northern Swan Coastal Plain of WA about 500 m inland of the beach on the coastal dunes. A single nearly homogenously vegetated habitat was surveyed in December 2004. The vegetation in the study area comprised of clumps of tall shrubs over a dense heath. Trapping consisted of 700 pit trap and 1400 funnel trap nights over a period of seven nights. Both reptiles and mammals were included in the analysis. These data were used to assess objective E.

Reptile assemblage: Ora Banda, WA (our data)

We had 10 study sites at Ora Banda (Salmon Gums, Spinifex, Gimlet, Golden Arrow, Davyhurst, Security, Palace, Rose, Wendy Gully and Crossroads), which is about 50 km north of Kalgoorlie, WA (30°27′S, 121°4′E). 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.). All 10 study sites were located within 25 km of each other. Each site was located near the centre of a specific vegetation community and was considered a separate habitat for the purposes of this analysis. Data were collected during nine field trips between September 2000 and January 2003, and again in January 2004 using alternating 20 L PVC buckets and 150 mm PVC pipes joined by flywire drift fences. For the January 2004 survey, funnel traps were also used. The trapping effort per habitat per survey period at each site was 336 trap nights from September 2000 until January 2003, and for January 2004 it was increased to 1344 trap nights. All reptiles and mammals trapped were included in the analysis. Trapping data collected during January 2004 were used to assess objectives D and E. Data from the four January (01, 02, 03, 04) surveys were used to assess objective B. Data from September and December 2000, and January and April 2001 were used to assess objective C.

Reptile assemblage: Australind, WA (our data)

The Australind study site was 8 ha of mostly Marri/Jarrah/*Banksia attenuata*/Peppermint woodland on dry sandy soils. Australind is approximately 15 km north-east of Bunbury in WA (33°17′S, 115°41′E). The survey was undertaken in March 2005 over a period of six nights. We used 60 trapping lines each containing two pit traps and four funnel traps to give a total of 2160 trap nights. Only the data for reptiles were included in the analysis. These data were used to assess objective D.

Reptile and mammal assemblage: Yanchep, WA (our data)

We surveyed two habitat types at Yanchep (31°32′S, 115°39′E), both with a grey sand substrate. One was a *Banksia* woodland and the other a closed Parrot Bush heath. Pit traps and funnel traps were used, and the total trapping effort was 3510 trap nights in the *Banksia* woodland and 880 trap nights in the Parrot Bush. We used the reptile and mammal data to assess objective D.

Reptile assemblage: Atley, WA (our data)

Thompson (1996) intensively surveyed a small area in the semiarid mulga woodland over a scattered spinifex grassland on Atley Station in WA (28°25′S 119°07′E). Sixty pit traps joined by drift fences were sampled over a period of 28 days during September and November–December (1680 trap nights). These data were used to assess objective D.

Reptile assemblage: Tanami Desert, Northern Territory (Hobbs *et al.* 1994)

Hobbs *et al.* (1994) investigated the influence of pit trap configuration on what was caught in the Tanami Desert (50 km south of The Granites; 20°32′S 130°24′E). Pit traps joined by drift fences were located on the flat sandplain dominated by spinifex. We have used their reptile data for four of the configurations (designs 1–4); a total of 240 pit trap days for each configuration. There was no detectable difference in the samples caught for the first four designs. These data were used to assess objective D.

Reptiles and mammal assemblage: Yallingup, WA (our data)

Two habitat types were surveyed on the south coast of the south-west of WA near Yallingup (33°40′S, 115°02′E). One site was a peppermint and eucalypt woodland and the other a closed heath. Each site contained 15 trapping lines, each consisting of two pit traps and four funnel traps joined by a drift fence. Each site was surveyed for nine nights to give a total trapping effort of 1080 trap nights per site. These data were used to assess objective D.

Reptile assemblage: Bungalbin, WA (our data)

Bungalbin (30°24′S, 119°38′E) is a gently undulating sandplain site, covered with small shrubs (predominantly *Melaleuca* spp. and *Acacia* spp.), sedges and perennial grass clumps of spinifex (*Triodia* spp.). Six sites, each having five lines of six pit traps (150 mm PVC pipes; 30 in total per site) and six funnel traps, were sampled during December 2002 and February 2003 (2628 trap nights for each period). These six sites represent slightly different vegetation communities and were within 6 km of each other. Only reptiles were used in the calculation of species accumulation curves. These data were used to assess objective A.

Data analysis

Where available, we used the number of individuals caught for each species for each trapping period in our

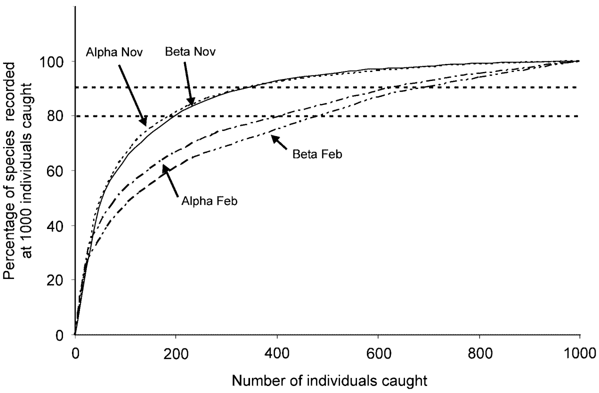

Fig. 1. Species accumulation curves for two sites at Cataby when surveys were undertaken during November and December with species richness estimated at 1000 individuals caught.

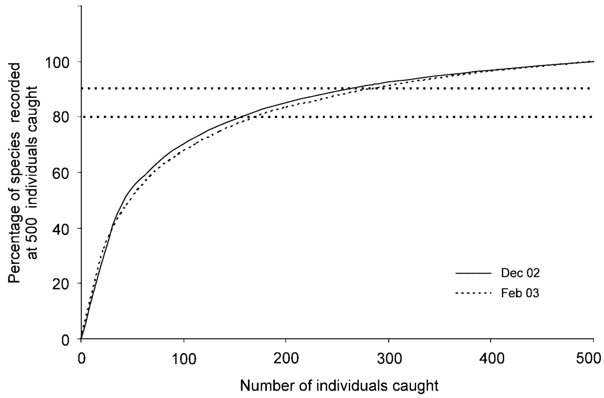

Fig. 2. Species accumulation curves for a December and a February survey at Bungalbin with species richness estimated at 500 individuals caught.

analysis. Otherwise we randomly allocated the number of individuals caught for each species over the number of trapping periods (Thompson and Thompson 2007). For each data set we calculated an averaged species accumulation curve using 10 000 random iterations of the survey periods without replacement using EstimateS (Colwell 1997). A non-linear regression curve was then calculated using the Beta-P model (Thompson *et al.* 2003) in NLREG software (Sherrod 2001). We plotted species accumulation curves with the ordinate axis as a percentage of the estimated species richness. We only used species accumulation curves that formed a 'reasonable' asymptote for species richness when assessing the number of individuals that should be caught to determine the number of individuals required to record either 80% or 90% of the species at a site.

On the abscissa of species accumulation curves we used the number of individuals caught rather than sampling effort to account for difference among surveys in species richness and abundance, and trapping efficiency (Moreno & Halffter 2001; Willott 2001).

RESULTS

A: Different seasons

We used the survey of reptiles and mammals caught at our Alpha and Beta sites at Cataby during November 2003 and February 2004 and for December and February at Bungalbin to assess differences in species accumulation curves for the same habitat but in different seasons (Figs 1,2). The predicted number of species caught after 1000 individuals were caught at Cataby was used as the estimate of species richness to calculate the percentage on the ordinate axis. The number of individuals caught in the November surveys was adequate to accurately assess species richness (i.e. species richness predicted at 1000 individuals caught and the species accumulation curve asymptotes were similar, and they were also close to the actual number of species caught, Table 1; the species accumulation curve had formed an obvious plateau, Fig. 1). However, there appears to be an inadequate number of individuals caught for both February surveys to obtain reasonable asymptotes (see difference between actual and predicted species richness; Table 1), and thus estimates of species richness. The shape of the curves (Fig. 1) indicated that there are appreciable seasonal differences in the trapped assemblage structure but this is almost certainly due to an inadequate number of individuals being caught in February. The number and percentage of singletons, and singletons and doubletons caught in the November was less than for the February survey (Table 1), and this probably contributed to the species accumulation curve asymptotes for February being too high.

The shape of the two species accumulation curves for the combined data for the six sites at Bungalbin surveyed in December 2002 and February 2003 are similar (Fig. 2), although the number of individuals caught in February was much less than in December (284 *vs* 157; Table 1). Predicted species richness at 500 individuals caught was about what would be expected for the combined data for the six sites (we have surveyed these sites each year since 1990). These data indicate little seasonal variation in the shape of species accumulation curves for similar faunal assemblages in close proximity. This meant that the number of individuals required to be caught to record 80% and 90% of the species present were very similar (Fig. 2).

Table 1. Number of individual reptiles and mammals caught, the number (and percentage) of singletons, and singletons and doubletons, with the predicted number of species recorded after 1000 individuals were caught at Cataby and 500 individuals caught at Bungalbin, and the species accumulation curve asymptotes for both sites

	Cataby					
	Alpha		Beta		Bungalbin	
	Nov 2003	Feb 2004	Nov 2003	Feb 2004	Dec 2002	Feb 2003
Individuals caught	568	296	449	254	284	157
Species caught	27	23	32	22	34	30
Predicted species at 1000 individuals	27.98	30.76	34.09	33.07		
Predicted species at 500 individuals					37.14	38.42
Species accumulation curve asymptote	28.27	293.69	35.67	2225.68	45.26	53.52
Singletons (*n*/%)	2 (7)	6 (26)	3 (9)	8 (36)	7 (21)	8 (27)
Singletons and doubletons (*n*/%)	7 (20)	9 (39)	4 (12)	11 (50)	11 (32)	12 (40)

Table 2. Number of individual reptiles and mammals caught, with the predicted number of species recorded after 1000 individuals were caught and the species accumulation curve asymptotes for 10 sites at Ora Banda

	Jan 2001	Jan 2002	Jan 2003	Jan 2004
Individuals caught	606	515	401	828
Species caught	45	48	43	49
Predicted species at 1000 individuals	47.44	54.67	51.62	49.88
Species accumulation curve asymptote	57.03	122.90	139.20	61.04
Singletons (*n*/%)	5 (11)	11 (23)	12 (28)	7 (14)
Singletons and doubletons (*n*/%)	13 (29)	17 (35)	16 (37)	9 (18)

B: Same season but different years

We used the combined reptile data for 10 sites around Ora Banda for four successive January surveys to compare the shape of species accumulation curves to examine year-to-year differences. The trapping protocol was the same for the first three Januarys; however, for January 2004 we quadrupled the number of trap nights by adding the same number of funnel traps as we had pit traps, and we opened the traps for 14 nights instead of seven. When sufficient individuals were caught (e.g. January 2001, 2004) the species accumulation curves have plateaued at a 'reasonable' level, as it was similar to the estimated number of species recorded after 1000 individuals were caught and the asymptote Table 2. Species accumulation curves for January 2001 and 2004 are similar, as are the curves for January 2002 and 2003, where a lesser number of individuals were caught (Fig. 3). When an adequate number of individuals are caught, the species accumulation curves are of a similar shape and year-to-year differences are minimal.

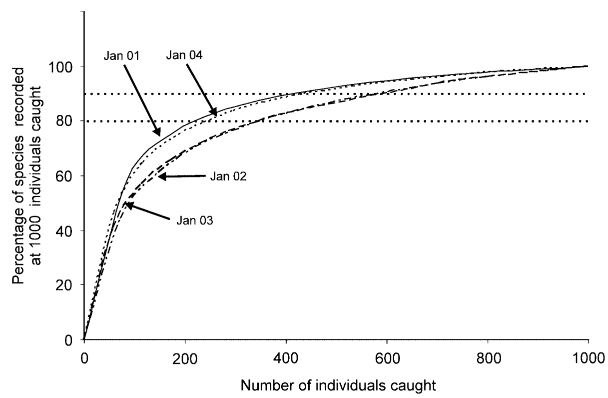

Fig. 3. Species accumulation curves for the combined data for nine sites at Ora Banda surveyed in January 2001, 2002, 2003 and 2004 with species richness estimated at 1000 individuals caught.

C: Cumulatively summing successive surveys

We used four successive surveys in spring (September), early summer (December) mid summer (January) and autumn (April) in 2000/01 for our Ora Banda data to assess how species accumulation curves change with the accumulation of data. As the number of individuals caught increased, the number of species caught increased from 41 in the September survey, to 50 after the December survey, to 54 after the January survey and remained unchanged for the April survey (Table 3).

The species accumulation curve for September (Fig. 4) is the most different and this is almost

Table 3. Number of individual reptiles and mammals caught, the number (and percentage) of singletons, and singletons and doubletons, with the predicted number of species recorded after 2500 individuals were caught and the species accumulation curve asymptotes for the combined data for all 10 sites at Ora Banda for four successive seasons in the 2000–2001

	Sep 2000	Sep, Dec 2000	Sep, Dec, Jan 2001	Sep, Dec, Jan, Apr 2001
Individuals caught	494	1125	1732	1968
Species caught	41	50	54	54
Predicted species at 2500 individuals	53.42	53.68	55.57	55.99
Species accumulation curve asymptote	91.89	60.14	63.39	63.90
Singletons (*n*/%)	10 (24)	6 (12)	5 (9)	5 (9)
Singletons and doubletons (*n*/%)	12 (29)	12 (24)	8 (15)	8 (15)

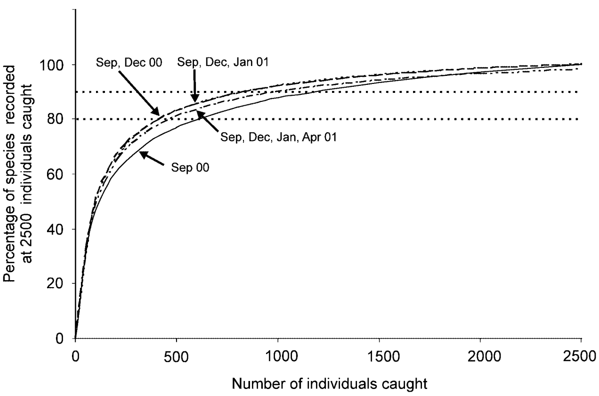

Fig. 4. Species accumulation curves for the combined data for nine sites at Ora Banda for successive surveys undertaken in September, December 2000, and January and April 2001 with species richness estimated at 2500 individuals caught.

certainly due to the lower number of individuals caught (Table 3). Increasing the number of species caught from a reasonably large starting point results in fewer singletons and doubletons in the data set. As the number of individuals caught increased with progressive surveys the species accumulation curves became more closely aligned, as did the accuracy of the estimate of the number of species recorded after 2500 individuals were caught and species richness predicted using the asymptote. There was no appreciable difference between the shape of the species accumulation curves for the combined September, December and January surveys and when the April survey data were included.

D: 80% and 90% of the species in a single homogenous habitat

To assess the number of individuals that need to be caught in a relatively homogenous habitat to catch an estimated 80% and 90% of the predicted species in that habitat we used our data from Cataby, Ora Banda, Cervantes, Australind, Atley, Yanchep, Yallingup and data from the literature for the Pilbara and the Tanami Desert. We only used data sets where the species accumulation curve had established an obvious plateau such that the asymptote was a reasonable estimate of species richness (Fig. 5). We used the predicted number of species caught after 1000 individuals were captured as the number of species in the habitat. We then calculated the number of individuals required to catch 80% and 90% of this number of species. The shape of the species accumulation curves varies appreciably among these data sets and this difference mostly reflects differences in the assemblage structure (Thompson & Withers 2003).

There is a positive curvilinear relationship between the number of trappable species in the assemblage and the number of individuals that need to be caught to record an estimated 80% or 90% of the species in the assemblage (Fig. 6).

E: 80% and 90% of the species in heterogeneous habitats

To assess the number of individuals that need to be caught in heterogeneous habitats to catch an estimated 80% and 90% of the predicted species we have used species accumulation curves for Roxby Downs and Ora Banda. The averaged species accumulation curve for Roxby Downs indicate that approximately 500 and 1800 individuals need to be caught to record 80% and 90% of the species, respectively (Fig. 7). Read (1995) described the Roxby Downs site as situated in an interdunal swale dominated by perennial shrubs, *Atriplex vesicaria* and *Maireana astrotricha*. He divided the site into five habitat types for analysis purposes. However, differences among habitat types appear to be much less than for the 10 Ora Banda sites. The species accumulation curve for the combined data for the 10 Ora Banda sites indicates that an estimated 80% and 90% of the species would be recorded after about 500 and 1800 individuals were caught, respectively (Fig. 7). The shape of the curves for Roxby Downs and Ora Banda are similar. It is not known if this shape characterizes faunal assemblages in heterogeneous habitats in arid and semiarid areas of Australia, as we were unable to find other suitable data sets.

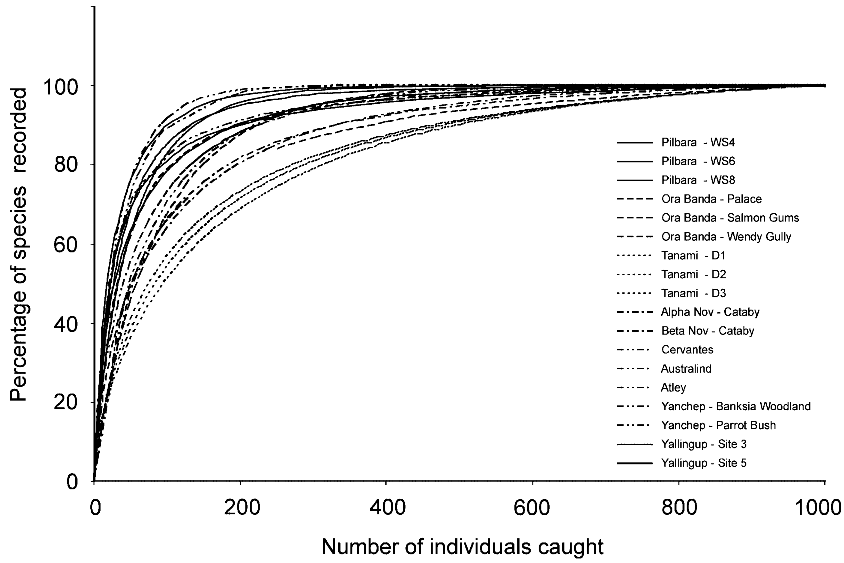

Fig. 5. Species accumulation curves calculated for 18 habitats with species richness estimated at 1000 individuals caught.

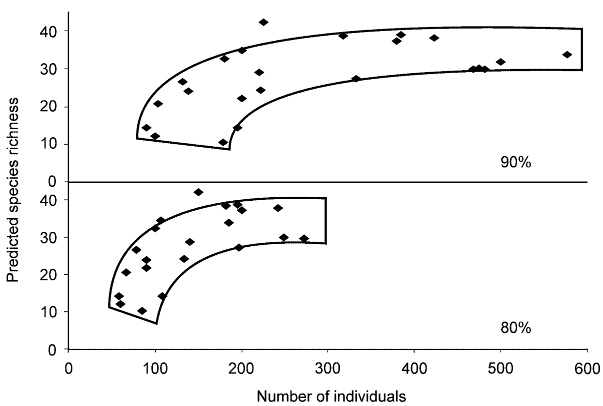

Fig. 6. Relationship between the number of individuals caught and predicted species richness in a habitat to catch 80% and 90% of the estimated number of species.

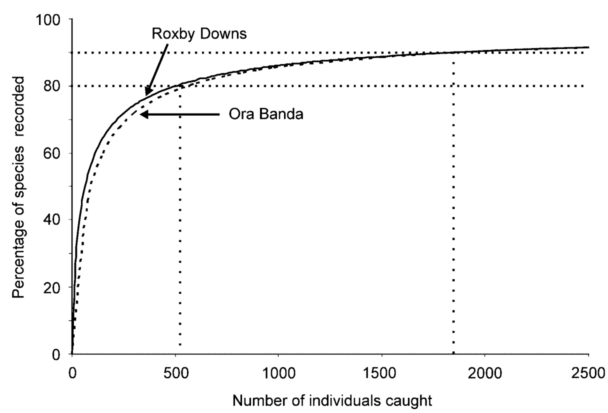

Fig. 7. Species accumulation curves for Roxby Downs and the 10 sites at Ora Banda in January 2004 with species richness estimated at the asymptote.

DISCUSSION

Obviously the most accurate method for determining faunal diversity at a site is to sample all of the individuals present (Rodda *et al.* 2001), but this is rarely possible and sampling to estimate species richness is therefore the only practical alternative (Colwell & Coddington 1994). Of the numerous parametric and non-parametric methods used to estimate species richness, species accumulation curves are a useful tool (Colwell & Coddington 1994). We know that the shape of species accumulation curves is influenced by species richness and evenness of species being sampled (Thompson & Withers 2003), and because we are sampling an assemblage, sampling error will also contribute to variation in the shape of species accumulation curves (Colwell & Coddington 1994). We also know that the shape of the curve influences the asymptote and thus the estimate of species richness.

Influence of sample size and rarely caught species

When there were few species and evenness was high, the species accumulation curve has a steep initial slope and plateaus earlier. Increasing the number of rare or seldom caught species in the assemblage results in a less steep initial slope, a less well defined shift to a plateau and most often the need to catch a higher number of individuals before an accurate estimate of species richness can be made from the asymptote of the curve. As with most methods of estimating species richness, a relatively large sample is necessary to

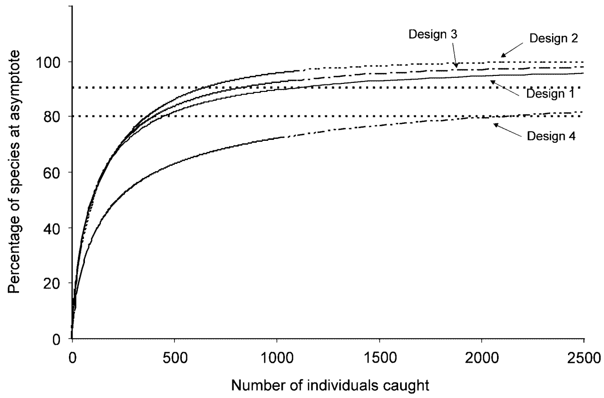

Fig. 8. Species accumulation curves for four pit-trapping configurations from the data contained in Hobbs *et al.* (1994) with species richness estimated at the asymptote.

obtain an accurate result (Melo & Froehlich 2001). However, even large samples do not always adequately address this problem. For example, the sample sizes that Hobbs *et al.* (1994) obtained to test the impact on catch rates of various trap layouts were between 1005 and 1068 for their first four designs. There are few examples in the literature of more than 1000 individuals being caught at a particular site during a pit-trapping program over a few years. An inspection of the four species accumulation curves in Figure 8 indicates that the curves for designs 1, 2 and 3 are similar and the asymptotes are almost identical (33.3, 33.2, 33.4, respectively). However, the species accumulation curve for design 4 is obviously different and predicted species richness using the asymptote is higher at 47 species. The percentage of singletons, and singletons and doubletons for designs 1, 2 and 3 (singletons 10%, 9%, 7%, doubletons 20%, 19%, 23%) are low and similar, but the percentage of singletons and to a less extent singletons and doubletons in the design 4 data set (21% and 29%, respectively) are much higher. The influence of these few rarely caught species has resulted in a flatter curve and a higher predicted species accumulation curve for design 4. Hobbs *et al.* (1994) concluded that there were no differences in the assemblages among four designs, although, the species accumulation curves indicate that the structure of the assemblages differed (see Thompson & Withers 2003).

Variability in activity patterns

A further confounding variable in the use of species accumulation curves to predict species richness and trapping effort is that the activity patterns of small terrestrial vertebrate fauna varies temporally (i.e. seasonally and year to year), with environmental variables such as ambient temperature, cloud cover, humidity and rain and often for no apparent reason. This variability in activity is directly linked to the propensity for an individual to be trapped, which affects the shape of the species accumulation curve (Thompson & Withers 2003). This issue is not addressed here. Within these constraints, is it possible to provide guidelines on the number of individuals that should be caught in a survey of small vertebrate terrestrial fauna to inventory a nominated proportion of the species in an area?

Different seasons

Where trapping effort was adequate for the species accumulation curve to plateau, as indicated by the similarity between the number of species actually caught, predicted species richness at 500 individuals caught and the asymptote of the species accumulation curve (e.g. Bungalbin, December and February surveys; Fig. 2), then the species accumulation curves were similar. However, when there was a marked difference between the number of species caught, the number of species estimated after 1000 individual captures and the asymptote, then shape of the curves differed (e.g. Cataby, Fig. 3). We interpreted this to indicate that there was little variation in the shape of species accumulation curves between seasons. However, when an inadequate number of individuals are caught resulting in a high proportion of singletons and doubletons in the sample, the species accumulation curve provides an inaccurate estimate of species richness.

Different years

Surveys in January 2001 and 2004 around Ora Banda caught a higher number of individuals than during 2002 and 2003. Estimated species richness based on 1000 captures and at the asymptote were similar for the 2001 and 2004 surveys, as were the shape of the two species accumulation curves. When a lower number of individuals were caught in 2002 and 2003, the species accumulation curve was less steep and the plateaus not as clearly defined, which is characteristic of an assemblage with a higher number of rare or less common species (Thompson & Withers 2003). When less individuals were caught, most species were caught in lower numbers and some can be perceived as being 'rare' and therefore flatten the shape of the curve and provide an asymptote that gives an unrealistic high estimate of species richness. This issue can be addressed, in part, by catching more individuals and this is best done by increasing the number of traps.

The shape of species accumulation curves did not differ appreciably from year to year for the same habitat when surveyed in the same season, but sufficient individuals needed to be caught so the shape of the curve and the asymptote provide a realistic representation of the assemblage. Insufficient captures can result in more singletons and doubletons which can alter the shape of the species accumulation curve and provide a poor estimate of species richness.

Cumulatively data summing for successive surveys

For Ora Banda the species accumulation curve for the first survey in September 2001 differed most from the others and the estimated species richness from the asymptote was too high. The inclusion of data from the next three surveys (December, January and April) changed the shape of the curve little, except it plateaued to provide a more accurate estimate of species richness. There were no appreciable differences in predicted species richness after 2500 individuals were caught or the asymptote by adding the April survey data to that from the first three surveys. These data suggest that it is desirable to accumulate data from successive surveys, but the order of the survey period must be randomized in the analysis (Thompson & Thompson 2007).

Trapping effort for 80% and 90% of species – heterogenous habitat

To detect 80% and 90% of the species at Roxby Downs and Ora Banda, approximately 500 and 1800 individuals, respectively, needed to be caught. The species accumulation curve for Ora Banda plateaued at 60 species which we believe is a reasonably accurate estimate of species richness, as we have caught 59 species after intensively surveying the area on 12 occasions over a period of 4 years. We therefore suggest that catching approximately 500 and 1800 individuals is necessary to record 80% and 90% of the species, respectively, in a heterogeneous habitat or multiple habitats in the same area.

Trapping effort for 80% and 90% of species – homogenous habitat

When sufficient individuals are caught, a species accumulation curve that plateaus will provide a reasonable estimate of species richness, and variation in its shape (e.g. Fig. 5) will be mostly influenced by species richness and the assemblage structure. Trapping samples containing a high proportion of singletons, and to a lesser extent singletons and doubletons, require more individuals to be caught to achieve an obvious plateau in the species accumulation curve than samples with fewer singletons and doubletons. Thus, there is a positive curvilinear relationship between the number of individuals that need to be caught and estimated species richness to detect 80% or 90% of the species in a habitat (Fig. 6). Much of the variability shown in Figure 6 is due to the number of singletons in the samples. The higher the number of singletons (and to a lesser extent doubletons), the flatter the species accumulation curve and the more likely the asymptote will poorly estimate species richness. A high number of singletons in a sample is most easily corrected by increasing the sample size. Increasing the sample size has three benefits: (i) it reduces the number of singletons; (ii) it increases the probability of catching additional species; and (iii) it increases the propensity for the species accumulation curve to have established a plateau to provide an asymptote that is a robust estimate of species richness.

Rare species

Some species are rarely caught and can therefore be perceived as being 'rare', which may imply that they have conservation significance. These species may indeed be rare, that is, they occur in low numbers in that habitat, but they may also be rare because they are 'transients' that belong in another habitat or have been forced out of their normal habitat. Some species that are relatively abundant may only occasionally be caught in the trapping protocols that are used. An appropriate change in the trapping protocols could change their perceived rareness. For example, the incorporation of funnel traps into an established pit-trapping program at Ora Banda caught a proportionally higher number of medium and large snakes, pygopods and more widely foraging, fast moving skinks. This is a strong argument for using a diverse range of trap types in surveys (e.g. pit traps, funnel traps, Elliott traps). For example, James (1989) reported catching two juvenile *Varanus giganteus* in his pit-trapping program. These large varanids are unlikely to be caught in pit traps, and only occasionally do juveniles get caught. Surveying on the cusp of the period when juveniles are present can therefore distort the perception of the abundance of species and thus alter the shape of the species accumulation curves and the prediction of species richness based on the asymptote. Similarly, some species appear to have a high propensity to avoid falling into pit traps (e.g. *Moloch horridus* and *Varanus eremius*), and only a small proportion of the available population are trappable. We would suggest that where it is obvious that individuals have been caught that would not normally be caught in that habitat or trap type (e.g. echidnas in cage traps; rabbits, owls, bats and *V. giganteus* in pit traps; cats in funnels traps), these data should be excluded from the analysis as they distort the shape of the species accumulation curve and the estimate of trappable species. Choosing which individuals/species to exclude from the analysis is obviously subjective and requires knowledge of a species ecology, movement behaviour and body size.

Trapping effort

Presuming a balanced range of traps are used for the terrestrial fauna surveys (e.g. pit traps, funnel traps and Elliott traps), we believe that based on the available information it is possible to provide a general guideline on the trapping effort required, at least for a relatively homogenous habitat in mesic or arid WA.

Figure 6 provides a useful guide as to the number of individuals that need to be caught to record 80% and 90% of the species for a habitat. For habitats that are relatively species poor (e.g. 10–15 species), then 70–100 individuals will record about 80% of the species, and 90–200 individuals will record about 90% of the species. The higher the proportion of rare species in the sample the higher the trapping effort that will be required. Where a habitat contains 35 species, then 100–280 individuals will need to be caught to record 80% of the species, and 200–600 individuals will need to be caught to record 90% of the species. Again, a higher number of individuals will need to be caught if the habitat contains a higher proportion of singletons and doubletons.

Before a field survey commences, it is often difficult to estimate species richness and relative abundance, and therefore predetermine the trapping effort required to catch 80% or 90% of species. However, a literature search and a search of museum records should indicate the species that might be found in that habitat.

For heterogeneous habitats, the issue is more complex because different habitats contain different faunal assemblages (Thompson *et al.* 2003). A combination of the number of habitat types and the difference in faunal assemblage structure among habitats will have a very large influence on the number of individuals that will need to be caught at these sites for the species accumulation curve to establish a plateau that is a robust estimate of species richness. Based on our data for Ora Banda and Roxby Downs, 80% of the trappable species will be recorded when approximately 500 individuals are caught, and 90% of the species when approximately 1800 individuals are caught.

Environmental consultants surveying heterogeneous habitats for the purposes of preparing an EIA often record considerably fewer than 500 individuals for an entire site and habitats at these sites are often more diverse and more dispersed across the landscape than was the case for Ora Banda and Roxby Downs. It is therefore apparent that such inventories of species are generally incomplete.

Undertaking fauna surveys to capture 70–200 individuals in a habitat or 500–1800 individuals in a heterogeneous habitat is both time-consuming and expensive. However, our findings demonstrate that it is possible for consultants to use sufficient survey effort to record 80% or 90% of the species in a habitat. Surveys at Cervantes, Yanchep, Australind and Yallingup were all done by an environmental consulting firm for the purpose of preparing an EIA and achieved this objective. Too often an inadequate survey effort results in the recording of 40–60% of the species in a habitat and the WA EPA accepts this as an adequate representation of the assemblage. Such limited surveys generally only record the common species and this information is often readily available by searching museum databases for the area (e.g. http://www.museum.wa.gov.au/faunabase/prod/index.htm). Therefore government regulators need to be very clear on the purpose and the objectives for these surveys. A more cost-effective alternative to field surveys with a low trapping effort is to obtain the same level of information by searching museum databases and conducting a literature review. The Western Australian Museum, for example, has in excess of 150 000 reptiles in its collection and specimens for most parts of the state. It is therefore likely that it will have a record of the commonly occurring reptile species for most areas of the state if a relatively wide search grid is used in *FaunaBase* (http://www.museum.wa.gov.au/faunabase/prod/index.htm). More explicit guidelines by government agencies (e.g. WA EPA) on the purpose of fauna surveys and the scale of the trapping program would address this issue.

Reporting results for fauna surveys undertaken for EIA

Terrestrial fauna surveys are undertaken during the preparation of an EIA to describe the potential impact of that disturbance on the fauna (EPA 2002). To achieve the EPA (EPA 2002) requirements for best practice, a higher level of survey effort than is currently used by many environmental consultants is required. We have demonstrated that species accumulation curves are a useful tool for indicating the adequacy of the trapping effort and the proportion of the species actually detected. Averaged species accumulation curves should be included in the reporting of fauna survey results as they provide a clear indication of the adequacy of the survey effort.

ACKNOWLEDGEMENTS

Much of the field work undertaken to support this research was financially supported by OMG Cawse

Nickel and Paddington Gold Pty Ltd for which we are very appreciative. Field work at Ora Banda was undertaken with ethics approval granted by Edith Cowan University and licences issued by the Department of Conservation and Land Management. Field work undertaken at Cataby was done with the approval of the Animal Ethics Committee at the University of Western Australia and licences issued by the Department of Conservation and Land Management. Field surveys undertaken at Yanchep were financially support by Yanchep Sun City Pty Ltd, at Cervantes by LandCorp, at Australind by Marist Brothers Community Inc and Peet & Co Pty Ltd, and Yallingup by Canal Rocks Properties Group.

REFERENCES

Colwell R. K. (1997) *EstimateS: Statistical Estimation of Species Richness and Shared Species Samples.* [Cited 1 March 2006.] Available from URL: http://viceroy.eeb.uconn.edu/estimates.

Colwell R. K. & Coddington J. A. (1994) Estimating terrestrial biodiversity through extrapolation. *Phil. Trans. R. Soc. Lond. B* **345,** 101–18.

Environmental Protection Authority (2002) *Terrestrial Biological Surveys as an Element of Biodiversity Protection: Position Statement No. 3.* Environment Protection Authority, Perth.

Hayek L. C. & Buzas M. A. (1997) *Surveying Natural Populations*. Columbia University Press, New York.

Hobbs T. J., Morton S. R., Masters P. & 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. & Cooper N. K. (2002) Terrestrial small mammals of the Abydos Plain in the north-eastern Pilbara, Western Australia. *J. R. Soc. WA* **85,** 71–82.

How R. A. & Dell J. (2004) Reptile assemblage of the Abydos Plain, north-eastern Pilbara, Western Australia. *J. R. Soc. WA* **87,** 85–95.

How R. A., Newbey K. R., Dell J., Muir B. G. & Hnatiuk R. J. (1988) The biological survey of the eastern goldfields of Western Australia; Part 4, Lake Johnston – Hyden study area. *Rec. West. Aust. Mus., Suppl*. No. 30.

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

McKenzie N. L., Hall N. & Muir W. P. (2000a) Non-volant mammals of the southern Carnarvon Basin, Western Australia. *Rec. WA Mus. Suppl.* **61,** 479–510.

McKenzie N. L., Rolfe J. K., Aplin K. P., Cowan M. A. & Smith L. A. (2000b) Herpetofauna of the southern Carnarvon Basin, Western Australia. *Rec. WA Mus. Suppl.* **61,** 335–60.

Melo A. S. & Froehlich C. G. (2001) Evaluation of methods for estimating macroinvertebrate species richness using individual stones in tropical streams. *Freshwater Biol.* **46,** 711–21.

Moreno C. E. & Halffter G. (2000) Assessing the completeness of bat biodiversity inventories using species accumulation curves. *J. Appl. Ecol.* **37,** 149–58.

Moreno C. E. & Halffter G. (2001) On the measure of sampling effort used in species accumulation curves. *J. Appl. Ecol.* **38,** 487–90.

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

Rodda G. H., Campbell E. W. & Fritts T. H. (2001) A high validity census technique for herpetofaunal assemblages. *Herpetol. Rev.* **32,** 24–30.

Sherrod P. H. (2001) *Nonlinear Regression Analysis Program*. 6430 Annandale Cove, Brentwood, Tn, USA.

Soberón J. & Llorente J. (1993) The use of species accumulation functions for the prediction of species richness. *Conserv. Biol.* **7,** 480–8.

Thompson G. (1996) A lizard and snake census on Atley Station. *WA Nat.* **21,** 59–63.

Thompson G. G. & Thompson S. A. (2007) Using species accumulation curves to estimate trapping effort in fauna surveys and species richness. *Aust. Ecol.* **32,** 564–9.

Thompson G. G. & Withers P. C. (2003) Effect of species richness and relative abundance on the shape of the species accumulation curve. *Aust. Ecol.* **28,** 355–60.

Thompson G. G., Withers P. C., Pianka E. R. & Thompson S. A. (2003) Assessing biodiversity with species accumulation curves; inventories of small reptiles by pit-trapping in Western Australia. *Aust. Ecol.* **28,** 361–83.

Willott S. J. (2001) Species accumulation curves and the measure of sampling. *J. Appl. Ecol.* **38,** 484–6.