SPECIES RICHNESS AND ABUNDANCE OF BIRDS IN MT LOFTY RANGES STRINGYBARK HABITAT: 1999–2000 SURVEY

MAX L. POSSINGHAM, SCOTT A. FIELD, and HUGH P. POSSINGHAM

ABSTRACT

We surveyed the birds of stringybark woodland in the Mt Lofty Ranges of South Australia in 38 patches of relatively intact habitat; it is the first of a series of yearly surveys in the ranges. Each patch contained one 2 ha site that was sampled nine times from November 1999 to February 2000. Three 20 minute samples were taken on separate days and six consecutive 20 minute samples on a single day. This report places the data in the public forum by publishing species lists and some initial analysis and discussion of the basic data. These data are summarised in two lists, which categorise the records by species and site. For each species, two measures of abundance are calculated: probability of recording—called 'Reporting Rate' in *The new atlas of Australian birds* (Barrett *et al.* 2003)—and density. This information provides baseline data for comparison with the results of future surveys.

Given that *The new atlas of Australian birds* is mainly based on presence-absence data, we assessed the potential for translating presence data into density data by plotting density as a function of the probability of recording. Our statistical analysis gives a preliminary indication of the effect of survey parameters on the bird records. The analysis shows that observer, wind and site all had significant effects on the number of species recorded. We present a new model of how species count accumulates as a function of number of sites and number of visits to each site, thus providing an estimate of species richness. We also provide some recommendations for survey design and monitoring. The basic data are available from the authors and at www.ecology.uq.edu/downloads/birds.

INTRODUCTION

Since Ford and Howe (1980) expressed concern about the future of the birds of the Mt Lofty Ranges, postulating that even 'common' species are likely to disappear because of habitat loss, there has been little published work on the habitat preference and abundance of birds in the region. Paton, Carpenter and Sinclair (1994) provide comprehensive data on bird distribution using the 1984–85 *Second bird atlas of the Adelaide region* (SAOA 1994) that highlights a number of species that appeared to have declined in different parts of the region since the previous atlas in 1974–75 (SAOA 1977). However, the data share problems common to many atlases: the survey sites were not chosen in a systematic fashion; the survey effort was not uniform; the data were not spatially precise; the data were presence-absence; and the study provided only two snapshots of population trajectories, making interpretation difficult.

We embarked on a long-term yearly series of structured surveys (Collins 2001) of the birds of the Mt Lofty Ranges, while bearing in mind the growing community concern about the declining birds of the region, and the need for monitoring that could assess the effect of habitat restoration and other efforts to stem this decline. This paper reports on the results from the first year of surveys where we concentrated on obtaining basic measures of abundance and techniques for data analysis in a stratified sample of stringybark patches. We adopted the same methodology as *The new atlas of Australian birds* (Barrett *et al.* 2003) so that our results would be compatible with that extensive database and also contribute to the interpretation of the data.

The stringybark woodland habitat consists of an upper storey of brown stringybark *Eucalyptus baxteri* and/or messmate *E. obliqua* over a dense sclerophyllous understorey of acacias, banksias, leptospermums, hakeas, xanthorrhoeas, epacrids, various peas, etc. (see Specht 1972). It is the most common native habitat remaining in the region.

The formal structure of the survey provides baseline data for comparison with future surveys of the Mt Lofty Ranges. In particular, this paper includes:

- bird lists with the numbers of birds recorded, the number of times a species is sighted and the number of species recorded;
- an investigation of species accumulation plots across sites and visits as a means of estimating species richness, i.e. the number of species inhabiting this habitat;
- two estimates of bird abundance for selected species, i.e. the probability of recording a species and bird density; and
- the effect of survey design factors on the number of species recorded, enabling comments on survey design.

This preliminary analysis will enable us to refine our survey method (see also Field, Tyre and Possingham 2004).

SURVEY METHOD

During the period from early November 1999 to late February 2000, five observers visited 38 patches of stringybark woodland recording birds in 2 ha sites for 20 minutes following the method used for *The new atlas of Australian birds* (Barrett *et al.* 2003) (Figure 1). Observers recorded bird numbers in each of three categories: occupying or utilising the site (on-site); flying over (overhead transients); or outside (off-site). Observers were required to estimate bird numbers, and not to count an individual bird more than once during a 20 minute sample. They also needed to decide carefully whether flying birds were occupying the site, i.e. they were foraging within or above the canopy (e.g. swallows, martins, and birds of prey), or were overhead transients. Another decision was whether an aural observation was on-site, off-site or an overhead transient. Breeding activity and other observations were also noted.

Observers covered the site as best they could, given the occasionally relatively high vegetation density and rough terrain. The survey planners suggested a site boundary on the instruction sheet, e.g. a square (140 m sides), a circle (79.8 m radius), or a long rectangle (e.g. 70 m x 30 m) along a path. The 38 patches were chosen using ARCView GIS and GAR Map 1295, issued by Planning SA (1998), followed by an on-site visual inspection. The patches covered a range of sizes (1686 ha to 3.8 ha) throughout the Mt Lofty Ranges where stringybark woodland dominates (see Figure 1). The chosen sites had mature trees and relatively intact understorey and were at least 50 m from the edge of the patch and on a mid-slope (avoiding gullies and ridge-lines).

There were two series of samples at each site, hereafter referred to as 'Short' and 'Long' Surveys. The Short Survey comprised three 20 minute samples by different observers on different days and times. The Long Survey comprised six consecutive 20 minute samples totalling a 2 h visit by the same observer. For the purpose of isolating groups of samples for analysis, each visit to a site is termed a Session and each sample a Pass. 'Sessions 1, 2 and 3, Pass 1' constitute the Short Survey and 'Session 4, Passes 1 to 6' the Long Survey.

The bird records were entered onto record sheets together with observer initials, site number, date, start and end times and weather (with cloud as percentage cover; and temperature, wind and precipitation at five, four and four levels respectively). Note that each record is the total number of birds of each species sighted during a sample, so each record is often the result of many observations of individual birds of each species.

All analyses presented here, except the basic lists, ignore overhead transient and off-site records.

The data were entered into a *Microsoft Access 97* database for analysis.

RESULTS AND ANALYSIS

The five observers completed 342 record sheets during 114 hours of observation time, plus much more travelling time. The observations totalled 3,368 on-site, 2,057 off-site and 264 overhead transient records, each record being the sighting of one or more birds. The following sections present an analysis of these data with some discussion. The basic data are available from the authors and at:

www.ecology.uq.edu/downloads/birds.

Bird and species counts

It is important to note that the data presented in this paper refer to a specific set of conditions, namely the 2 ha sites in 38 specific stringybark woodland patches in late-spring and summer of 1999–2000, using particular observers and times of day. See Possingham and Possingham (1997) for discussion of these and other factors that affect bird observations.

Table 1 summarises the records for all species from both the Short and Long Surveys (comprising a total of nine samples) of the 38 sites; scientific names for these species may be obtained from Christidis and Boles (1994) or SAOA (1996). This table shows the number of birds of each species recorded on-site, off-site and as overhead transients; the number of birds and sightings for each survey; the number of birds for each sample; and the probability of recording a species, P_{re} (see below for method of calculation). In this table, note that 'one sighting' means the species was recorded once during either a Short or Long Survey. So, for the Short Survey, a species could be sighted a maximum of 114 (i.e. 38 x 3) times.

Table 1 also shows that 69 species were recorded overall, 55 on the 2 ha sites, 27 as overhead transients and 62 off-site. Of the 69 species, 14

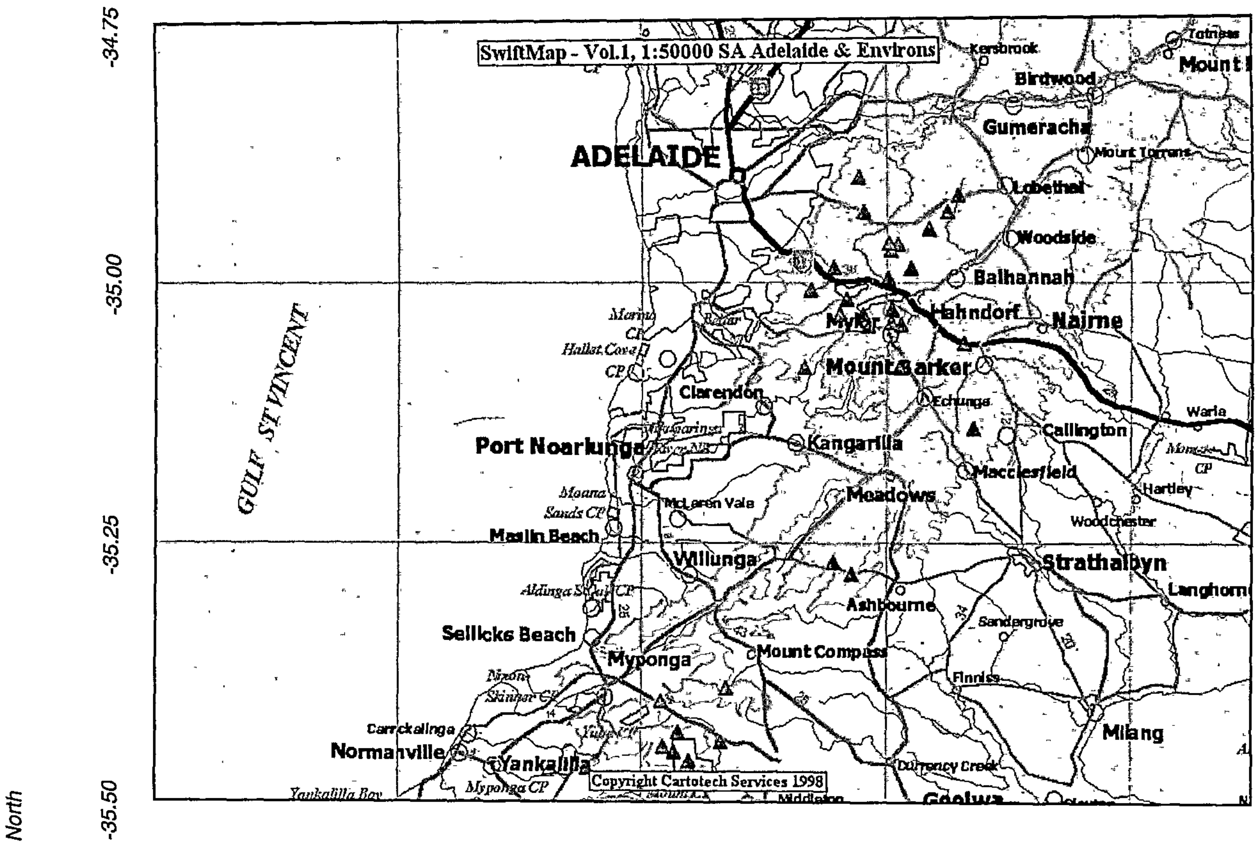

Figure 1a. Northern region

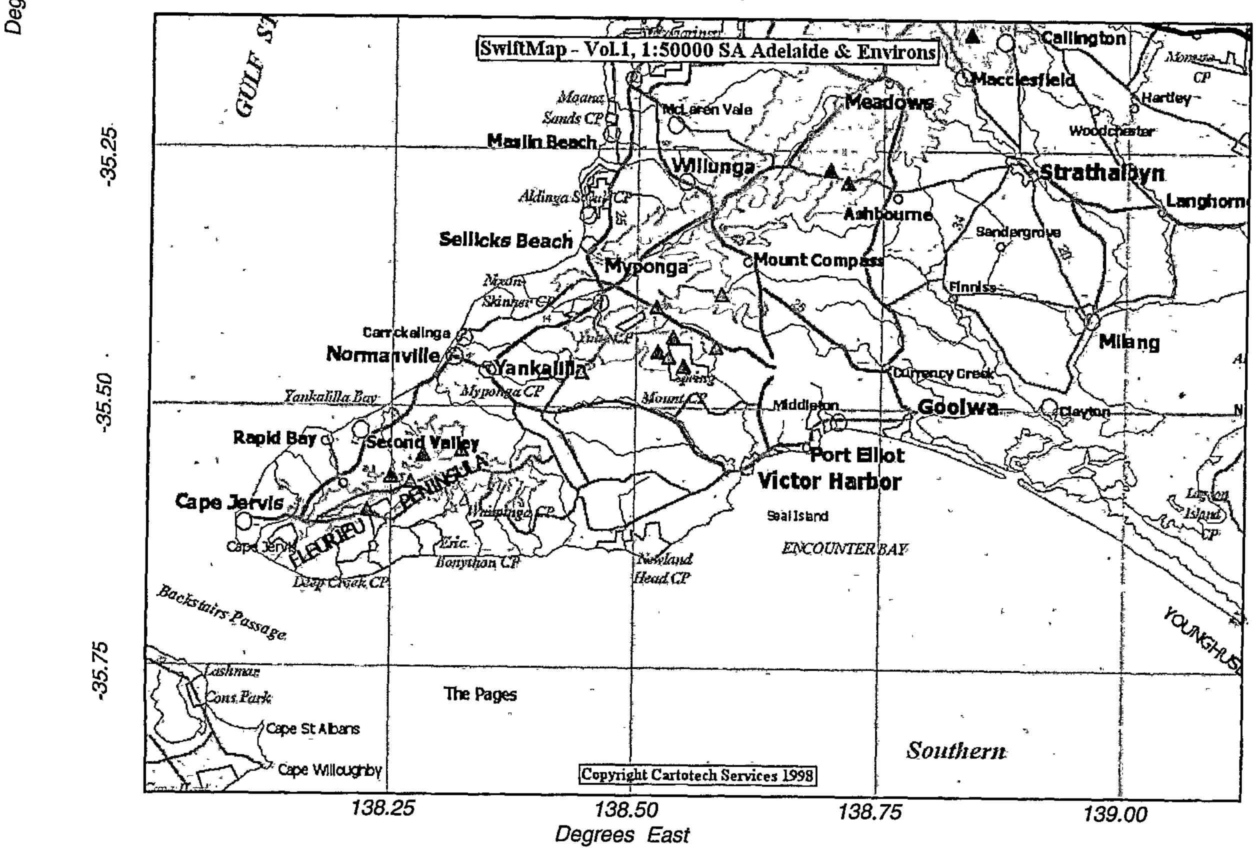

Figure 1b. Southern region

Table 1. All birds recorded for all 20 minute samples of thirty-eight 2 ha stringybark sites for the 1999–2000 survey. The data given are for on-site, overhead-transients or off-site records. Note that one sighting means that one or more single birds or several groups of birds were recorded during one 20 minute sample of a 2 ha site. The probability of recording a species P_{re} is the total on-site sightings for the four independent visits (Sessions 1 to 3, Pass 1 and Session 4, Pass 1) divided by the number of visits (i.e. 38 x 4 = 152). The total on-site sightings for these four visits are not given in Table 1, but can be obtained from 152 x P_{re}. The species marked #, ## and ### indicate on-site species commonly, uncommonly and rarely recorded, respectively; values of P_{re} equal to 0.6 and 0.13 are used for these divisions. Five other on-site species (marked with ?) were recorded at very low numbers and are either nocturnal species or may be considered vagrant in this habitat. Of the 14 species not recorded on a site, five are wetland species (marked *), six are not closely associated with stringybark (marked **) and three could well have occupied a site (marked ***).

		Short Survey					Long Survey								Summary Data			
Common Name		No. of sightings	Total birds recorded	Birds recorded, sample 1	Birds recorded, sample 2	Birds recorded, sample 3	No. of sightings	Total birds recorded	Birds recorded, sample 1	Birds recorded, sample 2	Birds recorded, sample 3	Birds recorded, sample 4	Birds recorded, sample 5	Birds recorded, sample 6	Total birds for both surveys (on-site)	Total birds, overhead transients	Total birds, off-site	Probability of recording, P_{re}
Australian Wood Duck	*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	4	–
Great Cormorant	*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–
Australian Pelican	*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3	–
Australian White Ibis	*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–
Wedge-tailed Eagle	**	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	1	–
Masked Lapwing	*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–
Rock Dove	**	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3	2	–
Spotted Turtle-Dove	**	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3	–
Common Bronzewing	###	9	11	4	4	3	8	8	1	1	3	1	2	–	19	1	24	0.066
Brush Bronzewing	###	4	4	1	2	1	7	7	1	1	–	1	2	2	11	–	20	0.033
Crested Pigeon	**	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–
Yellow-tailed Black-Cockatoo	##	22	45	16	17	12	37	87	6	29	12	8	16	16	132	92	214	0.171
Galah	###	13	32	12	6	14	15	40	6	9	7	4	6	8	72	91	217	0.099
Sulphur-crested Cockatoo	###	8	23	2	14	7	5	7	2	1	–	3	–	1	30	9	112	0.059
Rainbow Lorikeet	###	11	33	12	13	8	23	71	10	10	12	16	12	11	104	243	154	0.099
Musk Lorikeet	###	2	4	4	–	–	1	2	–	–	–	–	–	2	6	29	20	0.013
Purple-crowned Lorikeet	###	2	6	–	4	2	6	12	2	3	–	3	4	–	18	31	14	0.02
Crimson Rosella	#	75	266	101	78	87	150	529	85	74	84	86	94	106	795	27	282	0.671
Red-rumped Parrot	###	1	1	1	–	–	1	2	–	–	–	–	–	2	3	–	1	0.007
Elegant Parrot	***	–	–	–	–	–	–	–	–	–	–	–	–	–	–	18	–	–
Fan-tailed Cuckoo	###	9	9	1	4	4	15	15	–	1	3	2	3	6	24	–	3	0.059
Horsfield's Bronze-Cuckoo	###	3	4	3	1	–	–	–	–	–	–	–	–	–	4	–	1	0.02

Shining Bronze-Cuckoo	###	3	3	1	1	1	3	3	–	–	–	–	1	2	6	–	9	0.02
Southern Boobook	?	1	1	–	1	–	–	–	–	–	–	–	–	–	1	–	–	0.007
Australian Owlet-nightjar	?	1	1	1	–	–	–	–	–	–	–	–	–	–	1	–	–	0.007
Laughing Kookaburra	###	9	14	6	7	1	16	23	6	3	4	6	2	2	37	–	75	0.086
Sacred Kingfisher	###	8	11	7	2	2	7	7	1	–	–	2	2	2	18	–	25	0.059
White-throated Treecreeper	#	73	133	52	36	45	157	239	44	44	37	39	37	38	372	1	201	0.678
Superb Fairy-wren	#	88	381	136	115	130	161	727	141	105	103	142	100	136	1108	–	122	0.783
Spotted Pardalote	###	1	1	1	–	–	4	4	–	–	1	2	–	1	5	–	1	0.007
Striated Pardalote	##	56	113	49	33	31	120	228	28	38	35	35	45	47	341	3	59	0.486
White-browed Scrubwren	##	43	107	35	32	40	63	162	31	30	26	28	31	16	269	–	18	0.355
Chestnut-rumped Heathwren	###	2	3	–	2	1	2	2	–	–	–	1	1	–	5	–	–	0.013
Brown Thornbill	###	67	210	61	79	70	160	560	99	103	102	95	75	86	770		33	0.605
Buff-rumped Thornbill	#	8	22	10	2	10	30	67	7	12	10	12	9	17	89	–	11	0.072
Yellow Thornbill	?	1	4	4	–	–	–	–	–	–	–	–	–	–	4	–	–	0.007
Striated Thornbill	#	75	389	143	106	140	165	749	117	136	115	120	128	133	1138	–	75	0.678
Red Wattlebird	##	25	37	12	11	14	33	67	7	10	11	7	13	19	104	19	131	0.197
Little Wattlebird	***	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	7	–
Noisy Miner	***	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3	–
Yellow-faced Honeyeater	##	48	92	24	34	34	86	205	31	33	42	41	21	37	297	8	122	0.414
Brown-headed Honeyeater	###	1	1	–	–	1	8	11	1	1	1	1	2	5	12	3	4	0.013
White-naped Honeyeater	##	19	38	13	11	14	24	54	5	13	8	11	3	14	92	11	40	0.145
Crescent Honeyeater	##	42	91	36	18	37	84	165	29	30	25	30	26	25	256	–	91	0.375
New Holland Honeyeater	##	17	49	9	13	27	24	37	3	6	7	8	5	8	86	–	27	0.125
Eastern Spinebill	##	21	30	17	3	10	56	73	16	9	9	8	13	18	103	–	26	0.211
Scarlet Robin	##	24	29	13	9	7	35	40	4	5	5	11	10	5	69	–	26	0.178
Varied Sittella	###	4	16	–	8	8	7	19	3	3	3	5	3	2	35	–	–	0.033
Crested Shrike-tit	###	1	1	–	–	1	1	2	–	–	–	2	–	–	3	–	1	0.007
Golden Whistler	##	31	47	15	13	19	80	127	20	20	24	21	22	20	174	–	64	0.276
Rufous Whistler	###	2	3	1	2	–	–	–	–	–	–	–	–	–	3	–	5	0.013
Grey Shrike-thrush	##	50	62	27	18	17	95	121	21	18	22	19	16	25	183	–	178	0.441
Magpie-lark	?	–	–	–	–	–	2	3	–	–	–	–	1	2	3	–	60	–
Grey Fantail	#	99	238	87	73	78	172	443	73	64	81	72	70	83	681	–	163	0.849
Willie Wagtail	**	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–
Black-faced Cuckoo-shrike	##	19	21	5	10	6	36	44	8	8	6	11	4	7	65	1	24	0.178
Dusky Woodswallow	###	1	1	–	1	–	2	3	–	–	1	2	–	–	4	–	2	0.007
White-backed Magpie	###	6	16	2	6	8	23	44	9	9	4	12	4	6	60	8	401	0.066
Grey Currawong	##	25	39	20	12	7	29	42	13	2	8	1	10	8	81	1	148	0.23
Little Raven	###	6	9	3	–	6	16	24	4	2	6	2	2	8	33	20	169	0.059
Skylark	**	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–
Red-browed Finch	###	9	29	6	11	12	12	29	8	13	2	–	1	5	58	–	14	0.079
European Goldfinch	###	9	21	6	10	5	10	19	4	2	5	5	2	1	40	26	19	0.072
Mistletoebird	###	3	6	5	1	–	4	4	–	–	1	1	1	1	10	2	2	0.02
Welcome Swallow	?	1	1	–	1	–	–	–	–	–	–	–	–	–	1	2	–	0.007
Tree Martin	###	1	2	2	–	–	7	23	5	3	3	3	4	5	25	–	11	0.02
Silvereye	##	30	68	17	19	32	57	173	22	26	32	25	34	34	241	4	37	0.263
Common Blackbird	##	58	90	44	20	26	106	181	33	32	32	26	30	28	271	1	87	0.513
Common Starling	###	2	2	–	–	2	14	19	2	6	3	4	4	–	21	8	12	0.026
Single sample species totals		–		45	44	42	–		39	39	39	44	42	43	–	–	–	–
Group species totals (69 overall)		54			54		49			43			49		55	27	62	–

Table 2. Species counts for all 20 minute samples of thirty-eight 2 ha stringybark sites for the 1999–2000 survey. Overhead transient and off-site records are omitted. CP = Conservation Park, RP = Recreation Park.

Patch Data			Site Coordinates (degrees)		Species Count for both Surveys		Species Count for Short Survey (1 hour)				Species Count for Long Survey (2 hours)						
No.	Name	Area (ha)	East	North	Average[1]	Total	Total	Samples 1	2	3	Total	Samples 1	2	3	4	5	6
7	Deep Creek CP	1154.62	138.227	-35.60	8.5	**20**	**14**	8	7	9	**16**	10	7	6	9	9	8
69	Hindmarsh Falls	11.33	138.582	-35.442	9.5	**24**	**18**	9	7	12	**21**	10	13	7	9	10	9
71	Hazkett Road	85.86	138.589	-35.392	11.25	**23**	**20**	16	10	11	**17**	8	13	7	11	9	9
98	Belair CP	825.58	138.674	-35.01	8.5	**19**	**12**	11	5	9	**18**	9	8	9	7	8	12
113	Cleland CP	1024.75	138.698	-34.99	11	**25**	**21**	12	10	16	**15**	6	7	5	10	7	8
116	Morialta CP	1686.46	138.723	-34.903	6	**19**	**13**	7	5	9	**12**	3	7	7	7	7	7
120	Loftia Park	466.36	138.704	-35.033	8.25	**23**	**15**	10	11	6	**15**	6	5	5	3	3	10
128	Horsnell's Gully CP	534.72	138.729	-34.936	10	**23**	**14**	9	8	10	**21**	13	12	12	12	11	16
130	North Mt Magnificent	100.36	138.716	-35.281	8	**19**	**13**	12	5	5	**18**	10	10	9	10	10	12
135	Stone Reserve Heathfield	11.8	138.727	-35.033	10.25	**23**	**17**	11	9	8	**19**	13	10	10	14	8	5
160	Rangeview Road, Carey Gully	3.8	138.757	-34.973	8.75	**18**	**17**	6	12	9	**11**	8	9	8	9	8	8
162	Norris Hill, Aldgate	148.56	138.757	-35.028	10.25	**24**	**19**	9	16	4	**20**	12	14	15	12	14	17
165	1282 Greenhill Road, Carey Gully	6.4	138.763	-34.966	10	**19**	**16**	11	10	9	**15**	10	11	9	8	13	11
168	Chapel Hill Diggings, Echunga	44.55	138.765	-35.082	10	**25**	**17**	12	5	12	**24**	11	12	11	13	14	15
170	Mylor CP	66.52	138.767	-35.042	10.75	**24**	**20**	13	13	10	**19**	7	7	9	9	10	8
176	Wotton Scrub	153.55	138.776	-34.99	12.5	**25**	**23**	16	15	12	**16**	7	8	11	9	8	7
182	Filsell Hill, Deviation Rd, Forest Range	555.78	138.796	-34.952	11.75	**21**	**18**	13	9	14	**15**	11	5	6	7	5	7
191	Wicks Reserve, Forest Range	51.34	138.814	-34.953	9.25	**24**	**17**	14	6	6	**19**	11	12	12	13	9	11
211	Willis Rd, Flaxley	24.17	138.84	-35.142	8.75	**17**	**14**	8	9	11	**11**	7	6	5	6	8	7
973	Waterfall Creek	25.09	138.323	-35.542	14.75	**31**	**25**	14	16	15	**25**	14	20	17	15	16	16
974	Springs Road	50.57	138.284	-35.547	7.75	**21**	**13**	11	5	4	**20**	11	13	10	12	9	11
975	Range Road	79.63	138.284	-35.547	6.75	**18**	**10**	8	4	8	**17**	7	11	10	6	8	5
976	Second Valley Forest	10.98	138.251	-35.568	7	**15**	**14**	7	7	8	**9**	6	4	6	6	4	4
977	Spring Mount West	289.6	138.524	-35.448	10.25	**21**	**17**	12	8	11	**16**	10	8	10	10	5	8
978	Mylor Parklands	94.3	138.756	-35.041	9	**21**	**18**	12	9	9	**14**	6	10	13	7	5	6
979	Hender Reserve	29.86	138.711	-35.081	12	**24**	**20**	11	12	13	**18**	12	13	15	12	15	13
980	Kanangra	4.85	138.55	-35.461	10	**24**	**17**	6	12	11	**19**	11	10	8	9	4	9
981	Scott Creek CP	143.84	138.669	-35.082	9.5	**22**	**16**	10	8	10	**19**	10	7	12	13	10	9
982	Totness RP	42.53	138.831	-35.06	7.75	**23**	**15**	10	8	4	**20**	9	9	11	13	9	14
983	Mt George CP	125	138.753	-35.00	9.75	**21**	**15**	9	10	9	**18**	11	5	7	7	8	5
984	Lenswood RP	20.44	138.825	-34.92	17.5	**32**	**29**	19	21	17	**19**	13	12	7	12	11	12
987	Sugarloaf Hill, Myponga	39.5	138.446	-35.467	10.25	**19**	**17**	16	6	7	**16**	12	7	6	8	6	8
988	Gully Road, Carey Gully	11.1	138.754	-34.965	9.25	**19**	**16**	7	8	14	**16**	8	8	9	10	12	10
990	Twin Oaks	7.05	138.539	-35.433	16.5	**26**	**24**	15	16	18	**22**	17	18	14	14	11	15
995	Stock Rd, Longwood	14.78	138.734	-35.044	8	**23**	**14**	4	2	14	**20**	12	12	11	9	14	14
996	Heysen Trail, Myponga Rd	25.64	138.522	-35.404	8.5	**19**	**18**	15	6	8	**10**	5	2	4	4	4	10
998	Kyeema CP	250	138.7	-35.271	9.75	**20**	**17**	8	11	10	**13**	10	5	7	5	8	7
999	Spring Mount CP East	121.37	138.452	-35.452	12.25	**26**	**20**	10	15	10	**23**	14	15	16	15	14	16
	Average species count				**9.99**	**22.11**	**17.18**	**10.81**	**9.37**	**10.05**	**17.28**	**9.74**	**9.61**	**9.37**	**9.61**	**9.05**	**9.97**
	SD of species count				**2.39**	**3.49**	**3.80**	**3.3**	**4.06**	**3.46**	**3.76**	**2.92**	**3.84**	**3.3**	**3.28**	**3.33**	**3.54**

[1]Average of four independent samples.

were recorded not occupying a site, but most of these 14 were not 'bush-birds', where bush-birds are considered to be those associated with stringybark woodland with a scrub and heath understorey. Five (marked * in Table 1) were waterbirds, a further six (marked **) were terrestrial but not bush-birds and the remaining three (marked ***) are bush-birds that could conceivably have been recorded on-site.

The probability of recording a species in a 2 ha site during a 20 minute sample, P_{re} (last column of Table 1), has been computed directly from the number of sightings for each species over the four independent time-separate 20 minute samples (Sessions 1 to 3, Pass 1 and Session 4, Pass 1) divided by the total number of visits, i.e. 152. The reason for choosing Session 4, Pass 1 as one of the four independent samples is that the records from the following passes may be influenced by observer activity during the first pass. Although the temporal and spatial scales are different, this statistic is analogous to 'reporting rate' used to summarize survey records in *The new atlas of Australian birds* (Barrett *et al.* 2003). For a species with a small number of sightings, this figure suffers a large statistical uncertainty. As the statistic is based on presence-absence data, an appropriate measure of this uncertainty is a 90% confidence interval (CI) computed using the binomial distribution (Campbell 1974, p. 310). The size of the CI, and hence the degree of uncertainty, is dependent on P_{re}, as illustrated by the following examples, in which the 90% CI is expressed as a percentage of P_{re}:

(1) 20 sightings, $P_{re} = 0.13$, 90% CI = ± 35%;
(2) 50 sightings, $P_{re} = 0.33$, 90% CI = ± 19%; and
(3) 90 sightings, $P_{re} = 0.6$, 90% CI = ± 11%.

For the purposes of discussion later in this paper, we have divided the species into three arbitrary groups: commonly, uncommonly and rarely recorded. The six species with a P_{re} greater than 0.6, marked with a # in Table 1, are commonly recorded in this habitat; they were sighted more than 90 times during the 152 independent visits. At the other end of the scale, are the 28 species with a P_{re} less than 0.13 (sightings less than 20) that are least likely to be recorded; they are marked with ### in Table 1. The remaining 16 species have a P_{re} between 0.13 and 0.6 (sightings between 20 and 90) and are uncommonly recorded; they are marked with ## in Table 1. The remaining five species, marked with ?, were recorded at very low frequency and are either nocturnal birds or could be considered as vagrant in this habitat.

Table 2 shows how the number of species recorded in a sample varies over space and time. Species counts combined over all nine samples (three in the Short Survey plus six in the Long Survey) at the individual sites vary considerably, from 15 to 32. The Lenswood Recreation Park and Waterfall Creek sites have a high species count and the Second Valley Forest, and Willis Rd, Flaxley sites have a low species count. The average species count for each site over the four time-independent 20 minute visits (column heading 'Average') shows much the same variation over the sites as does the total species count, although the site ranking changes slightly.

A cursory examination of the physical and floristic structure of these sites does not explain the difference in species count. In our subjective assessment, tree height, the proximity of a gully and the peninsular effect (whereby species are affected by being close to the tip of a peninsula) may be correlated with site richness. The future collection of floristic and terrain data and its comparison with species count could provide some answers. Recher (1985) reports that a number of workers have related species richness to soil fertility and rainfall because of the effect of these factors on food resources. The effect of site on species count is considered later in 'The effect of survey design factors on species count' and the next section discusses 'Species richness' for this habitat. We have used 'species richness' of a particular habitat to mean the number of species using that habitat and the 'species count' from a survey such as that reported here, as the data source for estimating species richness.

Accepting that species count is a good indication of the bird-watching merit of a habitat, the following discusses how survey variables affect species count. The species counts for the individual 20 minute samples (see Table 2) show considerable variation, mainly caused by the normal statistical effects of sampling with some effects due to weather and observer differences. Clearly either a *single* 20 minute or a 1 h or 2 h sample of a *single* 2 ha site is not a useful measure of species count for a visit to a *single* site. Using Campbell (1974, p. 142) some statistical conclusions are given below about the average number of species likely to be recorded from a number of sites as birdwatching effort varies.

The average of the species count from the four independent 20 minute samples for the 38 sites, gives a 90% CI of 10 ± 6.2 species. This is the average return from a single 20 minute sample of a *single* site. The species counts from combinations of the 20 minute samples are obtained by combining the records ignoring duplicate sightings. Combining the records from the Short Survey (three independent 20 minute samples) gives a 90% CI of 17.2 ± 6.4 for the total species count for a *single* site. Combining the records for the first 1 h from the Long Survey (three consecutive 20 minute samples) gives a 90% CI of 14.0 ± 6.0 for a 1 h visit to a *single* site, that is somewhat less than the 17.2 species count for a 1 h effort (plus travelling time) spent on separated samples. Combining the records from the Long Survey (six consecutive 20 minute samples) gives a 90% CI of 17.3 ± 6.4 for a 2 h visit to a *single* site, that is, no effective improvement over the Short Survey. Combining the records from the Short and Long Surveys gives a 90% CI of 22.1 ± 5.9 for the average species count for nine visits to a *single* site, an increase in the average, but a very similar spread. These figures show how an increase in bird-watching effort increases the resulting average species count. The relatively large 90% CIs could indicate that the differences are marginally significant. These data are inserted into Table 3 in the next section and discussed there.

If an observer makes the visits described above to a number of sites, e.g. N, then the species counts stated above are the best estimates of the single site average that would be obtained, but the 90% CI is reduced to $CI/\sqrt{N}$ and the species count differences would be more significant. If, however, the observer's records are combined or accumulated, then the species count will increase to about 50 as the number of sites increases to 38 (Figure 2). See the section titled 'Species accumulation plots' for comment on this effect.

Field, Tyre and Possingham (2002), using a more sophisticated statistical comparison of the three different day samples (Short Survey) with the six same day samples (Long Survey) concluded that about the same number of species is recorded by the Long and Short Surveys.

Survey efficiency

Using species count as the criterion, the Short Survey of a 1 h effort spread over three different 20 minute samples reported more species (54) than the Long Survey (49 species) from a 2 h visit. This 2 h visit is also only marginally better, in terms of species count, than the two 1 h visits (yielding 49 and 43 species, respectively) obtained by splitting the 2 h visit. The 54 species from the Short Survey is also very close to the 55 recorded for the whole survey, again indicating the merit of time-separated samples.

However, in considering the efficiency of the various combinations of 20 minute samples, it is important to consider the time spent surveying. Appendix 1 assumes a recording period of 5 h per day, including 1 h to travel to and from the survey region and 45 minutes to move between sites, to compute the hours per sample as shown in Table 3.

Whether one is concerned with the data for 38 sites or single sites in Table 3 depends on the purpose of the survey. Single site data are relevant to a survey of a regional group of unrelated sites, where an average species count over the region is not appropriate. We are using the data from this stringybark survey to indicate likely results from surveys of other habitats. Single visits (0.23 species per hour) are the most efficient, although a single 1 h sample is probably as good (0.2 species per hour). Using repeated samples invokes the 'law of diminishing returns' with the species count per hour falling through 0.17, 0.13 to 0.11 as two, three or four repeats are used, respectively. See the next section on species accumulation plots for more information on this topic. Of course, if the survey is based on 1 h samples of the 2 ha sites, the species count will be higher, changing from 10 to 14 for this survey.

The data for 38 sites refer to the total species count accumulated over samples of the 38 sites and so refers to the stringybark habitat. Single 20 minute visits result in nearly 1.0 species per hour and are the most efficient use of time. Again the law of diminishing returns applies for repeated samples. If a high species count rather than a high species count per hour is desired, the use of four independent 20 minute visits is more appropriate.

For estimating bird density, where bird numbers are relevant, all the survey designs give compatible results. The only benefit of repeated sampling is the smaller confidence intervals resulting from larger sample sizes.

Species accumulation plots

A species accumulation plot is a graphical display of how the number of a species observed in a

Table 3. Species per hour and bird density compared with effort surveying 38 sites for six survey designs. The calculations for designs 1 to 4 are based on the birds recorded from the four independent 20 minute samples, so averages are valid. For one sample, design 1, the maximum and minimum of the four possible values are quoted. For the two and three samples, designs 2 and 3, the maximum and minimum of all combinations of pairs and threes are quoted. For four samples, design 4, the average over the four is quoted. For the 1 h sample, results from the first and second 1 h periods of the Long Survey are quoted. It is not valid to use the average of the three 20 minute samples constituting a 1 h sample as they are correlated. Instead, the maximum of the three bird numbers for each species is used as the most representative of a 1 h sample. The same process is used for the 2 h sample.

	Survey design	Effort			Totals for 38 sites		Averages for single sites		
		Hours per sample[1]	No of samples	Total hours	Species count[2]	Species per hour	Species count[3]	Species per hour	Bird density[4] (birds/ha)
1	Single 20 minute samples:	1.14	38	43	39–45	0.91–1.0	10	0.23	11.3–13.5
2	Two independent 20 minute samples:	1.14	38 x 2	87	51	0.59	14.3	0.17	11.6–13.2
3	Three independent 20 minute samples:	1.14	38 x 3	130	54	0.42	17.18	0.13	12.1–12.8
4	Four independent 20 minute samples:	1.14	38 x 4	173	55	0.32	18.8	0.11	12.4
5	Two independent 1 h samples:	1.85	38	70	43–49	0.61–0.7	14	0.2	13.8–14.4
6	One 2 h sample:	2.9	38	110	49	0.45	17.28	0.16	14.8

[1] See Appendix 2 for calculation of effort in hours per sample.
[2] See Table 1. Species counts for the combination of multiple samples of a site ignores duplication of species.
[3]See Table 2.
[4] In this table, density refers to a 20 minute sample of a 2 ha site and is computed from the total number of birds of all species recorded; hence the values are larger than those in Table 4 for a single species.

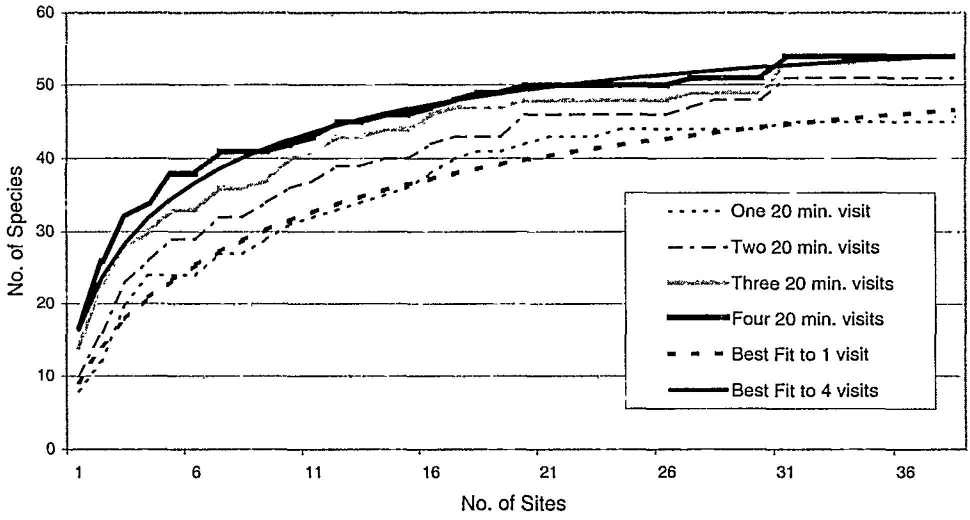

Figure 2. Species accumulation of four 20 minute samples of thirty-eight 2 ha stringybark sites for the 1999–2000 survey. These curves refer to one fit to the field data that gave $S_m = 63.8$, $M = 5.9$, $j = 0.76$ and $k = 0.52$.

particular habitat or region increases as the effort made to record them increases. Naturally the total number of species recorded increases as the recording effort becomes larger, eventually approaching a maximum. This maximum is an estimate of species richness of the habitat or region. A mathematical fit to repeated samples may be used, by extrapolation, to estimate species richness without actually making a large number of field observations.

In most studies, researchers focus on the question of how the species count accumulates as the recording effort over a habitat or region increases (Colwell and Coddington 1994). Here we explore how well species accumulation plots are able to estimate species richness and allow us to understand the relative efficiency of sampling widely over many sites across the landscape or repeated samples of relatively few sites.

Colwell and Coddington (1994) and Soberon and Llorente (1993) contain background information on fitting mathematical equations to accumulation plots. As a means of representing species accumulation from samples in both space and time, we propose an extension of the Clench equation (see Appendix 2) to include both the number of sites, s, and the number of visits, t, to each site, i.e.:

$$S = \frac{s^j t^k S_m}{(s^j t^k + M)}$$

where:

- S is the number of species for t visits to s sites;
- S_m is the maximum value of S;
- s is the number of site visits;
- t is the number of time visits to each site;
- M is a measure of how quickly species accumulate;
- j defines the relative effect of site visits; and
- k defines the relative effect of time visits.

This equation is possibly more general than necessary, but is used to obtain the relationship between species richness estimates and effort in space and time.

For large values of t or s or both, S approaches S_m, and when the total number of visits, $s\ t$, is such that $s^j t^k = M$, then S is one half of S_m and for $s^j t^k = 2M$, S is 66% of S_m. The value of S_m is an estimate of species richness for the habitat surveyed and M may be used to indicate how many visits are needed to record a certain percentage of habitat richness. The ratio k/j defines the relative efficiency of additional site and time visits in accumulating species. The equation assumes that time and site visits are interchangeable and all sites are identical in representing the avifauna of the habitat.

The equation may be changed to the form used by Colwell and Coddington (1994), i.e.:

$$S = S_m - \frac{M\,S}{s^j t^k}$$

which may be interpreted as S being equal to the maximum, S_m, less the proportion of S that decreases as $s^j t^k/M$ increases.

All the records constituting the 54 on-site species from the four time-separated 20 minute samples of the 38 sites were used to form the accumulation plots. The best estimates of the values of the four parameters S_m, M, j and k are obtained by minimising the squared differences between the theoretical accumulation plot and the accumulated species count from the recorded data. The order of the sites and times used to form the accumulation plots may be varied to give a number of sets of the four parameters. From the 24 possible sequences of the time visits and the numerous possible sequences of the 38 site visits, nine were randomly selected. The nine sets of the four parameters gave means and 90% CIs (Campbell 1974, p. 142) of: $S_m = 65 \pm 4.2$, $M = 5.6 \pm 0.79$, $j = 0.68 \pm 0.09$, and $k = 0.63 \pm 0.09$. Figure 2 shows the results of one such fit with $S_m = 63.8$, $M = 5.9$, $j = 0.76$ and $k = 0.52$. The mean ratio $k/j = 0.92$ with a 90% CI of ± 0.1, is a measure of the effectiveness of additional time visits compared with site visits. Thus our data indicate that additional site visits are a little more effective than additional time-separated visits to the same sites, but the CI of k/j is quite wide. This is to be expected as an additional site visit varies both time and space, whereas an additional visit to the same site varies only the time.

Some of the statistical variation in these four parameters will be caused by the fact that not all sites were visited on the same four days by four different observers, a difficult experimental design to achieve.

So, as the number of visits or sites becomes very large, one might expect to record a maximum species count of about 65 with a 90% CI of ± 4: this is an estimate of the species richness of stringybark woodland in the Mt Lofty Ranges.

Referring to a list of species inhabiting South Australia (SAOA 1985), some 85 species are listed as moderately common or common in the Mount Lofty Ranges, Southern Regions or Widespread in the State. Waterbirds, waders and some birds of prey are omitted from this total. Adding about another eight species that are summer visitors indicates that between 85 and 93 species are likely to be recorded in a survey of this nature.

Bird density and probability of recording

The data from this survey can be used to estimate bird density. Bird numbers recorded for a single 20 minute sample of one of the 38 plots vary widely, for example, from 15 to 0 for the Crimson Rosella *Platycercus elegans*. So, one could conclude that the density of the Crimson Rosella is between 7.5 and 0 birds/ha, hardly useful information.

The average number of birds recorded for the four time-separated samples of the 38 plots has been used to determine density. Results are given in Table 4 for the species with 19 or more sightings for those four samples. Figure 3 shows the relationship between density, D, in birds/ha, and the value of P_{re}. The figure also shows an exponential fit

$$D = -\frac{\log(1 - P_{re})}{1.2}$$

to the data, using the method of least squares. For species with densities less than 0.5 a linear relationship would be satisfactory.

This relationship was investigated as a means of converting P_{re} into bird density. P_{re} is identical to Reporting Rate as used in the RAOU bird atlases (Blakers, Davies and Reilly 1984; Barrett *et al.* 2003).

Regarding the 1 h and 2 h samples, a brief inspection of the relationship between density and P_{re} shows good agreement with the values for the 20 minute samples, particularly for the larger values where the percentage error (at least for P_{re}) is smaller.

It is worth noting that the bird density values in Table 3 refer to all the species recorded on-site rather than the single species density values given in Table 4.

The effect of survey design factors on species count

Here we analyse the influence of some factors on species count from a sample. Some of the most likely factors that affect the number of species recorded during a sample are the variations in vegetation structure, floristic content and nutritional level of the sites, landscape context of the site, time-of-day of the visits, observer ability and weather.

The aims of the survey design were not to study the effect of these factors, so they were not varied in a systematic manner and a rigorous statistical analysis is not possible. One exception is site, since all were sampled by four time-separated visits. Extreme conditions of wind and precipitation were avoided thus further restricting the analysis of the effect of weather. The time-of-day that the records were made was converted into time-after-sunrise in hourly units.

Tables 5, 6 and 7 give the average and standard deviation of the species count for the four time-separated 20 minute samples over the range of observers, wind strengths and visit times. The regression analysis tools in *Microsoft Excel* were used to give a preliminary indication of the importance of these factors. Of interest is that visit time does not significantly effect species count. All weather factors, other than wind, were found to have no significant effect on species count.

Although the sites were chosen, as far as possible, to be typical stringybark woodland, some differences in species richness between sites are evident from Table 2. The regression analysis gave $P < 0.001$[1] and indicated that the effect is an average increase of about seven species from the poorest to the best site.

The independence of the time-separated samples was checked by analysing the relationship between the number of days between the four samples of each site and the change in species count. Of the 152 visits, one sample had zero days separation, 17 had a single day separation and 35 had two to five days separation. An analysis of variance of the relationship between the difference in species count and the days-separation of the samples from 0 to 5 days, using *Microsoft Excel 97*, indicated that this effect is not significant.

[1]If it is assumed that there is no effect of this factor, then the P-value is the probability of the differences in average species count being due to random variation. A P-value less than 0.05 is usually considered to indicate a significant factor and less than 0.01, a highly significant factor.

Table 4. Density and probability of recording of selected species for four time-separated 20 minute samples of thirty-eight 2 ha stringybark sites for the 1990–2000 survey. This table includes only species sighted 19 or more times from the four time-separated samples, i.e. from 152 visits. * = species sighted between 20 and 50 times, with P_{re} between 0.13 and 0.33, and are considered to give less reliable results than those with more than 50 sightings. # = species sighted more than 90 times, with P_{re} greater than 0.6.

	Common name	No. of visits when sighted	Average no. of birds per visit when sighted	Probability of recording	Density (birds/ha)
*	Yellow-tailed Black-Cockatoo	26	2.0	0.17	0.17
#	Crimson Rosella	102	3.4	0.67	1.15
#	White-throated Treecreeper	103	1.7	0.68	0.58
#	Superb Fairy-wren	119	4.4	0.78	1.72
	Striated Pardalote	74	1.9	0.49	0.46
	White-browed Scrubwren	54	2.6	0.36	0.45
#	Brown Thornbill	92	3.4	0.61	1.02
#	Striated Thornbill	103	4.9	0.68	1.66
*	Red Wattlebird	30	1.5	0.20	0.14
	Yellow-faced Honeyeater	63	2.0	0.41	0.40
*	White-naped Honeyeater	22	2.0	0.14	0.14
	Crescent Honeyeater	57	2.1	0.38	0.39
*	New Holland Honeyeater	19	2.7	0.13	0.17
*	Eastern Spinebill	32	1.4	0.21	0.15
*	Scarlet Robin	27	1.2	0.18	0.11
	Golden Whistler	42	1.6	0.28	0.22
	Grey Shrike-thrush	67	1.2	0.44	0.27
#	Grey Fantail	129	2.4	0.85	1.02
*	Black-faced Cuckoo-shrike	27	1.1	0.18	0.10
*	Grey Currawong	35	1.5	0.23	0.17
*	Silvereye	40	2.3	0.26	0.30
	Common Blackbird	78	1.6	0.51	0.40

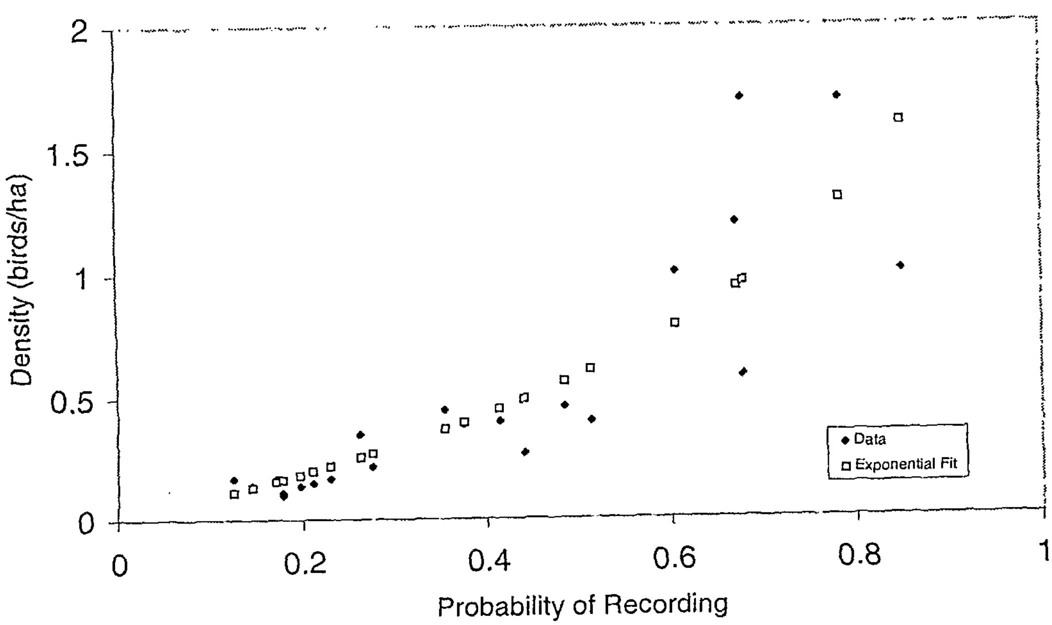

Figure 3. Density versus probability of recording birds from four 20 minute samples of thirty-eight 2 ha stringybark sites for the 1999–2000 survey.

Table 5. The effect of observer on species count (average and SD) over 150 visits of 20 minutes by four observers (P < 0.001)[1].

Analysis of species count	Observer 1	Observer 2	Observer 3	Observer 4
No. of visits	35	77	28	10
Average species count	11.25	10.31	8.04	7.80
SD	3.08	3.36	3.52	2.15

Table 6. The effect of wind on species count (average and SD) over 152 visits of 20 minutes in four levels of wind strength (P = 0.01)[1].

	Wind strength			
Analysis of species count	Calm	Light	Medium	Strong
No. of visits	53	75	22	2
Average species count	11.0	9.8	8.2	8.0
SD	3.8	3.2	2.9	2.8

Table 7. The effect of visit time on species count (average and SD) over 152 visits of 20 minutes at eight starting times (P = 0.5)[1].

	Starting times after sunrise in 1 hour periods							
Analysis of species count	0	1	2	3	4	5	6	7
No. of visits	9	38	32	24	23	21	4	1
Average species count	9	9.74	10.66	10.42	9.87	9.29	11	11
SD	3.32	3.45	3.2	4	2.44	4.27	4.76	–

[1]See footnote on p. 163.

DISCUSSION

The species lists and analysis presented here provide some basic data on the avifauna of stringybark woodland in the Mt Lofty Ranges. Overall, 69 species were recorded during the survey; 55 of these were using the 2 ha sites and the remainder were flying over or outside. The #, ## and ### marks in Table 1 show the bush-birds commonly, uncommonly and rarely recorded, respectively. Table 2 shows that a birdwatcher visiting a single 2 ha site of stringybark habitat in the Mt Lofty Ranges for 20 minutes could expect to record an average of about 10 species, but this will vary considerably depending on the particular site. Sampling the sites on three time-separated 20 minute visits (the Short Survey) will increase the species count to an average of about 17. However sampling the sites for six consecutive 20 minute periods (the Long Survey) yields a very similar result, i.e. about an average of 17 species. Combining the results for both surveys yields 22 species, on average. This shows how birdwatching results increase, i.e. from 10 to 17 to 22 species, as effort increases, but note that the spread (CI) remains about the same.

Species richness

Accumulation plots, using the data from the survey, have provided estimates of species richness of the stringybark woodland habitat surveyed. This process allows the estimate of species richness to extend beyond using species counts from the field data (e.g. the 55 species recorded for nine visits to 38 sites) to the expected species count from a survey of a large number of sites repeated a large number of times.

The figure of 65 ± 4 species from the accumulation plots falls short of an expected figure of between 82 and 95 species obtained from the SAOA Field List (SAOA 1985). The difference is likely to be that the 20 additional species are those that rarely use the stringybark habitat. We must also decide which species to include in the analysis, e.g. to concentrate on the core species of the habitat, and whether the survey method we have used is suitable for assessing their presence. We have deleted water birds from the analysis, but included nocturnal birds and some raptors, e.g. Brown Goshawk *Accipiter fasciatus* is included, but Swamp Harrier *Circus approximans* is not. The question arises about the suitability of the survey method for obtaining suitable records of these species. Should species be included that strongly prefer other habitats but are occasionally recorded in stringybark woodland, e.g. White-plumed Honeyeater *Lichenostomus penicillatus* and Crested Pigeon *Ocyphaps lophotes*? Perhaps when the other core habitats in the Mt Lofty Ranges, e.g. gum woodland, heath swamps, are surveyed and the purpose of the survey is defined, e.g. conservation issues, these matters will be resolved.

Another interesting result from the accumulation equation derived from the data is that sampling the sites at additional times is almost as effective at adding to the species count as sampling additional sites.

Measures of abundance

The processes used for estimating bird abundance described in this paper, P_{re} and density, appear satisfactory for common species in that the high values of P_{re} have small confidence intervals. However larger sample sizes (more visits to more sites) are needed for uncommon species to increase the precision of P_{re} and reduce the difficulty in assessing changes in abundance.

An examination of the relationship between density and probability of recording, Table 4 and Figure 3, shows that six species have P_{re} greater than 0.6. Two of these species, White-throated Treecreeper *Cormobates leucophaeus* and Grey Fantail *Rhipidura fuliginosa*, fall well below the fitted curve, indicating a relatively low density for a high recording rate P_{re} because usually there are only one or two of these birds per sighting. The remaining four species, Crimson Rosella *Platycercus elegans*, Superb Fairy-wren *Malurus cyaneus*, Brown Thornbill *Acanthiza pusilla* and Striated Thornbill *A. lineata*, are above the fitted curve confirming that they are often observed (usually in small groups), e.g. birds per sighting between 3.4 and 4.9 (see Table 4).

Note that the relationship we obtained between density and probability of recording only applies to bush-birds in stringybark habitat. Other species in other habitats will show a different relationship, e.g. the Little Corella *Cacatua sanguinea* will occur with a small probability of being recorded, but at high density when recorded, and Brown Falcon *Falco berigora* will be often recorded, but at a very low density.

Species commonly recorded

Six species, marked # in Table 1, have a P_{re} greater than 0.6 (Table 4), indicating that they are the species most likely to be recorded in stringybark habitat. However, note the comments on the relationship between probability of recording and density in the previous section. It raised the question of what is meant by a 'common' species. Does it mean a high density or a high chance of being recorded? For non-flocking species, the terms are likely to be equivalent but this is not so for flocking species.

Species rarely recorded

Many of the 28 species in this category, with a P_{re} value less than 0.13 and marked with ### in Table 1, are wide-ranging and not vulnerable in other habitats in South Australia or Australia, e.g. the cockatoos, lorikeets and cuckoos. Their low abundance in the Mt Lofty Ranges is of little national concern. However, of this 28 there are 15 bush-birds that could be of concern in stringybark or throughout the Mt Lofty Ranges and should be monitored to detect any change:

Common Bronzewing *Phaps chalcoptera*
Brush Bronzewing *P. elegans*
Fan-tailed Cuckoo *Cacomantis flabelliformis*
Horsfield's Bronze-Cuckoo *Chrysococcyx basalis*
Shining Bronze-Cuckoo *C. lucidus*
Sacred Kingfisher *Todiramphus sanctus*
Spotted Pardalote *Pardalotus punctatus*
Buff-rumped Thornbill *Acanthiza reguloides*
Brown-headed Honeyeater *Melithreptus brevirostris*
Varied Sittella *Daphoenositta chrysoptera*
Crested Shrike-tit *Falcunculus frontatus*
Rufous Whistler *Pachycephala rufiventris*
Dusky Woodswallow *Artamus cyanopterus*
Red-browed Finch *Neochmia temporalis*
Mistletoebird *Dicaeum hirundinaceum*

Species uncommonly recorded

Sixteen species between the two extremes are marked with ## in Table 1 and it may be considered satisfactory for them to remain at this abundance in this habitat if they are not threatened in other habitats either in South Australia or Australia. However, if their relatively low abundance in the Mt Lofty Ranges is of concern, surveys such as this, if repeated on a regular basis, could highlight species that are on a downward trajectory and be used to trigger recovery actions at an early stage before the species reaches the 'rarely recorded' category and intervention most likely becomes prohibitively expensive. The Scarlet Robin *Petroica multicolor,* which is commonly thought to be in decline in south-eastern Australia, is perhaps a case in point.

Robust detection of any change in species abundance, even those that are uncommon at present, may also require data to be collected and analysed over a number of years, possibly several decades, to account for natural inter-annual variation.

Survey design

The data in Table 3 show that single 20 minute visits to 2 ha sites are a more efficient use of survey time than multiple independent 20 minute visits or 1 h or 2 h visits for recording most species in 38 sites in this habitat. The additional time used for multiple samples would be better spent on increasing the number of sites surveyed and so obtain a better representation of the habitat. For estimates of density, all survey designs here have equal efficiency; the only benefit in increasing sample size will be the reduction in confidence limits of the estimate.

The above is supported by the work on accumulation plots, where it is shown that sampling the same sites at additional times is no more efficient than sampling additional sites. However, it may be necessary to conduct an initial survey and subsequent analysis to establish this fact when surveying an unknown habitat.

An analysis of the effects of other survey factors indicated that site, observer ability and wind have a significant effect on species count and starting time up to five hours after sunrise has little effect. The high effect that site has on species count suggests that the sites should be carefully selected for uniformity if a particular habitat is of interest.

General observations

This paper provides survey designers/managers concerned with bird species abundance and richness with the means of relating the objectives of the survey to many of the survey design factors. In addition it provides some indication of the important factors to be considered in survey design but more statistically biased designs will be needed to isolate these effects. More attention could be focused on site selection and the analysis of the effect of site parameters on species count.

This baseline survey, when sites in gum woodland and possibly other habitats are included, will provide statistical information concerning the avifauna of the Mt Lofty Ranges. When pursued over a long time period, the results may assist the study of bird species' decline and help determine whether conservation activities have a positive effect on avifaunal biodiversity.

ACKNOWLEDGMENTS

We thank David Paton, Penny Paton, Ryan Incoll and Vicki-Jo Russell for discussions about the design and implementation of this survey. Steve Ball and Keith Martin collected some of the data used in this paper. The Mapping software was supplied by MAPLAND, Environment and Geographic Information, Department for Environment and Heritage (DEH). Research was supported in part by a large Australian Research Council grant to Hugh Possingham. Survey effort was financially supported by DEH. We thank the referees and editor for their constructive comments on a draft of this paper.

REFERENCES

Barrett, G., Silcocks, A., Barry, S., Cunningham, R., Poulter, R. 2003. *The new atlas of Australian birds.* Birds Australia, Melbourne.

Blakers, M., Davies, S.J.J.F. and Reilly, P.N. 1984. *The atlas of Australian birds.* RAOU and Melbourne University Press, Melbourne.

Campbell, R.C. 1974. *Statistics for biologists.* Second Edition. Cambridge University Press, London.

Christidis, L and Boles, W.E. 1994. *The taxonomy and species of birds of Australia and its territories.* RAOU Monograph 2, Melbourne.

Collins, S.L. 2001. Long-term research and the dynamics of bird populations and communities. *Auk,* 118, 583-588.

Colwell, R.K and Coddington, J.A. 1994. Estimating terrestrial biodiversity through extrapolation. *Philosophical Transactions of the Royal Society of London,* 345, 101-118.

Field, S.A., Tyre, A.J. and Possingham, H.P. 2002. Estimating bird species richness: how should repeat surveys be organised in time? *Austral Ecology,* 27, 624-629.

Field, S.A., Tyre, A.J. and Possingham, H.P. 2004. Optimising allocation of monitoring effort under ecological and observational constraints. *Journal of Wildlife Management.* (In press).

Ford, H. and Howe, R. 1980. The future of birds in the Mount Lofty Ranges. *South Australian Ornithologist,* 28 (4), 85-89.

Hilborn, R. and Mangel, M. 1997. *The ecological detective.* Monographs in Population Biology, Princeton University Press, New Jersey.

Paton, D.C., Carpenter, G. and Sinclair, R.G. 1994. A second bird atlas of the Adelaide region. Part 1: Changes in the distribution of birds: 1974–1975 vs 1984–1985. *South*

Australian Ornithologist, 31 (7), 151-193.
Planning SA. 1998. *Floristic mapping of South Australia, southern Mt Lofty Ranges*. Information and Data Analysis Branch, Planning SA, Department for Transport, Urban Planning and the Arts, Adelaide.
Possingham, M.L. and Possingham H.P. 1997. Habitat use and abundance of dryland birds in heritage areas in the upper South-East of South Australia. *South Australian Ornithologist*, 32 (8), 145-160.
Recher, H.F. 1985. Synthesis: A model of forest and woodland bird communities. In *Birds of eucalypt forests and woodlands: ecology, conservation, management*. A. Keast, H.F. Recher, H. Ford and D. Saunders (eds). RAOU, Melbourne, pp. 129-135.
Soberon, J.M. and Llorente, J.B. 1993. The use of species accumulation functions for the prediction of species richness. *Conservation Biology*, 7, 480-488.
Specht, R.L. 1972. *The vegetation of South Australia*. Second Edition. Government Printer, Adelaide.
SAOA. 1977. *A bird atlas of the Adelaide region*. SAOA, Adelaide.
SAOA. 1985. *A field list of the birds of South Australia*. Third edition. SAOA, Adelaide.
SAOA. 1994. A second bird atlas of the Adelaide region. Part 2: Distribution maps 1984–1985. *South Australian Ornithologist*, 31 (8), 195-265.
SAOA. 1996. List of English and scientific bird names recommended for use in papers submitted to the *South Australian Ornithologist*. Supplement, *South Australian Ornithologist*, 32 (6), i-viii.

M.L. Possingham: 10 River St, Marden, 5070 S.A., Australia; e-mail <mlposs@ace.net.au>

S.A. Field: The Ecology Centre, The University of Queensland, St Lucia, 4072 Qld, Australia

H.P. Possingham: The Ecology Centre, The University of Queensland, St Lucia, 4072 Qld, Australia

Received 29 March 2002; accepted 6 November 2003

APPENDIX 1

For a survey extending over a 80 km x 20 km region, most observers travelled each day either from Adelaide (a large city nearby) or another convenient base, to a small region containing four or five sites. So the parameters relating to the computation of survey effort, in hours, are:

S = The total time for a recording period.
T = The average time to travel to the survey region and back.
t = The average time to travel between sites, including the time to walk from transport and return.
s = The sample period.
N = The number of samples in each recording period.

From the expression $S = T + (N - 1)\,t + N\,s$,

$$N = \frac{S + t - T}{s + t}\ .$$

For 20 minute samples, $S = 5$, $T = 1.0$, $t = 0.75$, $s = 0.33$, gives $N = 4.38$, i.e. observers expect to achieve 4.38 samples in a 5 h recording period. For 1 h samples, the only change is $s = 1$ giving $N = 2.7$. For 2 h samples, the only change is $s = 2$ giving $N = 1.73$. These figures for N must be considered indicative of averages for N as observers will survey one, two, three, four or five (not 4.38, 2.7 or 1.73) sites during one visit to the survey region.

The survey rates in hours per sample are given by S/N, which are 1.14, 1.85, 2.90 respectively for the above three situations (i.e. 20 minute, 1 h and 2 h samples). These data, together with the number of species recorded, are used in Table 3 to compute species per hour of survey effort.

APPENDIX 2

The Clench equation is given by Sorberon and Llorente (1993) as:

$$S = \frac{S_m n}{(n + M)}$$

where: S is the number of species for n samples;
S_m is the maximum value of S; and
M is a parameter.

As the number of samples, n, increases, the species count, S, approaches S_m, with 50% of the species recorded when $n = M$. In our study number of visits is the number of sites visited, s, multiplied by the number of times each site was sampled, t, so n can be replaced by $s\,t$.

Because the number of additional species recorded is very likely different for a visit to an additional site, compared with an additional visit at a different time, it is necessary to scale site and time visits differently, replacing n with $s^j t^k$. This may seem unduly complex, but it is needed because:

1) visiting the sites at additional times will affect S differently from including additional site visits, so the parameter k is needed; and
2) by symmetry, visiting different sites will affect S differently from visiting the same site again, so the parameter j is needed.

Values of S_m, M, j and k are obtained by fitting the expression

$$S = \frac{S_m s^j t^k}{(s^j t^k + M)}$$

to the data using the method of least squares (Hilborn and Mangel 1997).